A Review of Contaminants on the Scotian Shelf and in Adjacent Coastal Waters: 1970 to 1995

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PREFACE

Human population growth and industrial activity in coastal areas and adjacent waters around the world have had a wide range of impacts on the marine environment. In Atlantic Canada, human activities have resulted in the release, both ongoing and accidental, of a range of contaminants—substances including heavy metals, organic chemicals including pesticides, PAHs and PCBs, organic carbon, bacteria—into the ocean. Typical sources include urban runoff, fossil fuel use, industrial emissions, sewage, erosion and consequent siltation in streams and rivers, agricultural activities, and atmospheric deposition, shipping, and oil spills to name a few.

Fisheries and Oceans Canada (DFO) under its mandate to manage marine fish stocks, ensure the integrity of fish habitat, and understand physical and chemical processes in the ocean, as well as its former role in ensuring quality of fish products for human consumption (now carried out by Health Canada, Canadian Food Inspection Agency) has carried out a wide range of studies related to naturally-occurring as well as man-made contaminants in the ocean. As well, DFO has been asked increasingly because of its expertise, to provide input to the assessment of major issues of marine contamination and to deal with issues such as monitoring the health of the marine environment and determining trends. As part of this responsibility and as a contribution to international as well as Canadian initiatives with respect to contaminants in the ocean, DFO in the early 1990s with funding from the Toxic Chemicals initiative of Environment Canada's Green Plan, carried out a range of studies of contaminants in the marine environment. Included were the production of several publications which provided an overview of existing knowledge of ecosystems and contaminant issues in Eastern Canada (White and Johns 1997, Gulf of St. Lawrence; Pierce *et al.* 1998, Gulf of St. Lawrence, Bay of Fundy and North Atlantic).

The present report is a background review of contaminants in inshore and offshore waters of the Scotian Shelf prepared in 1995-96 as part of one of these initiatives. Two separate reports, dealing respectively with contaminants in inshore and offshore areas of the Scotian Shelf were prepared — they have been combined here to form the current report. The review is more comprehensive than has been presented in other sources, and includes 'grey literature', consultants' reports, and environmental assessment documents, in addition to primary publications and published technical reports. No attempt has been made to critically review the quality of observations reported, which could vary depending on the source and objectives of the studies consulted. However many of the main information sources were known to be credible, through the reputation of responsible individuals and organizations, personal knowledge of circumstances associated with particular studies, as well as through publication of many of the results in primary literature. The most weight in our interpretations, however, is placed on results from primary publications. With a few minor exceptions, the review has not been updated, and so omits additional work which may have been done after 1995.

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ABSTRACT

A review of measurements of contaminant concentrations in water, sediments and biota on the Scotian Shelf (the continental shelf off Nova Scotia) and in adjacent coastal waters, shows both areas of significant contamination (major ports and industrial centres), and areas of negligible contamination and near pristine conditions. Major centres including Halifax, Sydney, and Port Hawkesbury/Point Tupper on the Strait of Canso, show evidence of past and present contamination by hydrocarbons, trace metals, PAHs, and PCBs and other synthetic organic compounds, related to marine and shore-based industries. Pulp and paper production, shipping and vessel maintenance activities, and steel smelting, as well as sewage releases and non-point source pollution, are the predominant sources of contamination. Smaller centres such as the multi-use harbours at Shelburne, the LaHave River estuary (the communities of Bridgewater, Brooklyn and LaHave), Liverpool, and Lunenburg, have elevated levels of contaminants in sediments, often above guidelines for ocean disposal. Some smaller fishing ports have shown excessive contamination of sediments from fish plant discharges of organic waste, and from fishing and vessel maintenance activity, including residues of tributyltin in the sediments in the vicinity of marinas, PCBs in sediments of some fishing ports, and PAHs in sediments from creosote-treated timbers. Major oil spills such as occurred in Chedabucto Bay (the sinking of the tanker *Arrow*) and the *Kurdistan* spill off northern Cape Breton Island, have caused longterm contamination of coastal sediments in some locations. In contrast, many coastal areas such as St. Margarets Bay, have low to negligible or baseline concentrations of contaminants. Contamination of coastal waters by fecal coliform bacteria is, however, increasing in extent. Contaminants in coastal waters tend to be concentrated in certain phases, in particular sediments, and in some cases exceed levels for ocean disposal. Levels of contaminants in water and biota, although elevated above background, are typically acceptable according to Canadian guidelines for environmental quality. In Sydney Harbour, however, lobster have concentrations of PAHs too high to permit human consumption. Reductions in levels of some forms of contamination of waters, sediments and biota have occurred in recent years.

Offshore areas of the Scotian Shelf show generally low levels of trace metals, hydrocarbons, PAHs and synthetic organic compounds (DDT and derivatives, PCBs and other chemicals), in part because of dilution with waters of the North Atlantic. Persistent marine litter is, however, a prevalent feature of oceanic contamination. Although some contaminants are released locally on the shelf—chiefly through marine transportation activity and offshore petroleum exploration and production—the bulk comes from other areas, including the eastern North American landmass as a whole, via atmospheric transport and outflow from the Gulf of St. Lawrence as well as releases from coastal areas. Mostly, however, there is little scientific data on contaminant levels and trends in the waters, sediments and biota on the Scotian Shelf, apart from that necessary to determine if 'safe' levels of key contaminants occur in fish, shellfish and fish products, which, in general, have been acceptable. Nonetheless, declines in levels of DDT in the marine ecosystem on the Scotian Shelf have been inferred from decreasing concentrations measured in the blubber of seals on Sable Island; and hydrocarbon concentrations in offshore waters declined in the 1970s to early 1980s. Increasing pressure from development and human activities will present a challenge to management of marine contamination in future.

RÉSUMÉ

L'examen des mesures des concentrations de contaminants dans l'eau, les sédiments et le biote de la plate-forme Néo-Écossaise (le plateau continental qui borde la Nouvelle-Écosse) et des eaux littorales adjacentes révèle à la fois des zones gravement polluées (grands ports et centres industriels) et des zones où la contamination est minime et où les conditions sont pratiquement intactes. Dans les grands centres comme Halifax, Sydney et Port Hawkesbury/Point Tupper, sur le détroit de Canso, on observe des traces de contamination passée et présente par les hydrocarbures, les métaux traces, les HAP, les PCB et autres composés organiques de synthèse, provenant des industries maritimes et terrestres. La production de pâtes et papiers, la marine marchande et les activités d'entretien des navires, les aciéries, les rejets d'eaux usées et la pollution diffuse sont les principales sources de contamination. Dans les petits centres comme les ports polyvalents de Shelburne, de l'estuaire de la rivière LaHave (localités de Bridgewater, Brooklyn et LaHave), de Liverpool et de Lunenburg, les sédiments présentent des concentrations élevées de contaminants, qui dépassent souvent les seuils fixés par les lignes directrices sur l'immersion en mer. Dans certains petits ports de pêche, on trouve une contamination excessive des sédiments due aux rejets de matière organique par les usines de transformation du poisson, aux activités de pêche et d'entretien des bateaux, avec notamment des résidus de tributylétain dans les sédiments à proximité des marinas, des PCB dans les sédiments de certains ports de pêche, et des HAP provenant du bois traité à la créosote. Les marées noires comme celles qui ont été causées par le naufrage du pétrolier *Arrow* dans la baie Chedabucto, puis par celui du *Kurdistan* au large du nord de l'île du Cap-Breton, ont provoqué une contamination à long terme des sédiments côtiers dans certaines régions. Par contre, de nombreuses zones côtières comme la baie St. Margarets présentent des concentrations de contaminants négligeables ou correspondant aux niveaux de fond. La contamination des eaux côtières par les coliformes fécaux est toutefois de plus en plus répandue. Les contaminants des eaux côtières tendent à se concentrer dans certaines phases, en particulier dans les sédiments, et dans certains cas dépassent les seuils fixés pour l'immersion en mer. Les teneurs en contaminants des eaux et du biote, quoique dépassant les niveaux de fond, restent généralement acceptables selon les normes canadiennes sur la qualité de l'environnement. Dans le port de Sydney, toutefois, les homards présentent des concentrations de HAP tellement élevées qu'ils sont impropres à la consommation. On observe depuis quelques années des baisses des concentrations de certaines formes de contamination des eaux, des sédiments et du biote.

Dans les zones hauturières de la plate-forme Néo-Écossaise, on note généralement des niveaux faibles de métaux traces, d'hydrocarbures, de HAP et de composés organiques de synthèse (DDT et dérivés, PCB et autres produits chimiques), ce qui est dû en partie à la dilution par les eaux de l'Atlantique Nord. Ce sont plutôt les déchets sauvages permanents qui caractérisent la pollution marine. Bien que certains contaminants soient rejetés localement sur la plate-forme – principalement par la marine marchande, la prospection et la production extracôtière de pétrole – le gros de la pollution provient d'autres régions, notamment de l'est du continent nord-américain, aussi bien par le transport atmosphérique et les eaux du golfe du Saint-Laurent que par des rejets dans les zones côtières. Dans l'ensemble, on dispose cependant de peu de données scientifiques sur les niveaux et les tendances des contaminants dans les eaux, les sédiments et le biote de la plate-forme Néo-Écossaise, mis à part celles qui sont nécessaires pour déterminer si les concentrations de certains contaminants mesurées dans les poissons et fruits de mer et dans les

produits qui en sont tirés sont sans danger – ce qui est généralement le cas. Toutefois, on a conclu à une baisse des teneurs en DDT dans l'écosystème de la plate-forme suite à la réduction observée de la concentration de ce composé dans le lard des phoques à l'île de Sable; en outre, les concentrations d'hydrocarbures dans les eaux du large ont baissé dans les années 1970 et au début des années 1980. Le développement et les activités humaines vont exercer une pression croissante qui constituera dans les prochaines années tout un défi pour la gestion de la contamination marine.

1. AN OVERVIEW OF CONTAMINANTS ON THE SCOTIAN SHELF AND IN ADJACENT COASTAL WATERS

1.1 INTRODUCTION

Human activities in coastal areas and in the waters over the continental shelf off Nova Scotia (and also in areas far removed) invariably have led to releases of a wide range of substances that otherwise would not occur, and therefore are known as contaminants. In extreme cases, contaminants impede use of the environment by marine organisms, and by humans themselves, for example limiting recreational use in the case of fecal coliform contamination; limiting consumption of fish from the sea; and damaging habitat. While contaminants and levels in the environment are measures of the extent of human impact, they are used increasingly to provide indicators of the extent of recovery of the marine environment from releases of contaminants which have been regulated and controlled under law in most developed nations. Availability of this information provides a benchmark in any studies to assess damage from coastal industrial activity, success of control or remediation, and to provide a broad assessment of the health of the marine environment of Atlantic Nova Scotia as a whole in relation to similar areas in adjacent seas, including the Gulf of St. Lawrence, Newfoundland waters, the Gulf of Maine, and other waters of the Northeastern US continental shelf.

1.2 GEOGRAPHIC BOUNDARIES

Contaminant information presented in this report has been gathered from studies of coastal and offshore waters of Nova Scotia on the Scotian Shelf, a part of the Eastern North American continental shelf off Nova Scotia. Having as its approximate outer limit the 200 metre depth contour, the Scotian Shelf extends from the intersection of the Laurentian Channel and northern tip of Cape Breton Island, southwestwards to Northwest Channel on the western margin of Browns and German Banks, and to the vicinity of Yarmouth[1] on the Atlantic approaches to the Bay of Fundy (Figure 1.1).

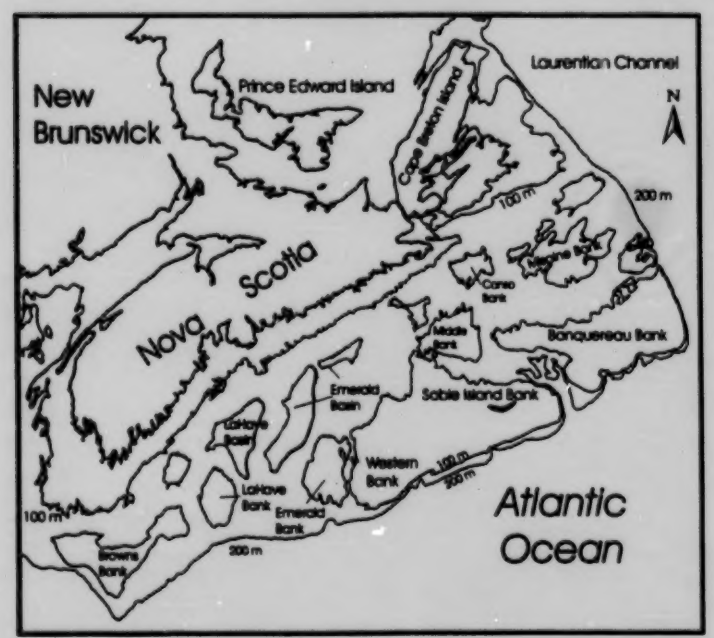


Figure 1.1. The Scotian Shelf.

[1] The choice of boundaries, however, excluded the major port of Yarmouth in southwestern Nova Scotia, from detailed overview of contaminants, although it is discussed in certain contexts.

To contrast the oceanography and behaviour of contaminants on the extensive oceanic areas of shelf, with those associated with the coast, the Scotian Shelf can be further divided into two zones: *inshore or coastal*—inlets, bays, estuaries, and waters of the outer coast shallower than about 100 metres; and *offshore*—all other areas. In practise, there is a gradual transition in environmental characteristics at the boundary between these zones.

In general, inshore areas experience a physical, chemical and biological regime which differs from that of deeper waters and greater distances (from several to tens of kilometres) from shore. They are areas in which marine plant and animal growth is most abundant; where influences of freshwater inflow are most important; where sedimentation is most significant; and also which are most clearly affected by human influences. Contaminants in these areas are discussed in Section 3, *Contaminants in Coastal Areas*. Beyond the coast is an area of transition, in which conditions rapidly become dominated by the influence of waters of the Atlantic Ocean. Although a sharp boundary in environmental characteristics between inshore and offshore parts of the Scotian Shelf does not exist, some resources (e.g. lobster) and features (e.g. shallow depth, coastal water masses) are more conveniently discussed in relation to inshore areas. Contaminants in offshore waters, extending from the inshore to the outer edge of the continental shelf at approximately 200 m, are presented in Section 2, *Contaminants in Offshore Areas*.

Although contamination of the marine environment can take many forms, our discussion focuses mainly on chemical contaminants (heavy metals and organic chemicals including pesticides, PAHs and PCBs). We present available data on levels in waters, sediments and biota, obtained from a wide range of sources, which by virtue of the absence of earlier data, cover the period from approximately 1970 to 1995. In addition, and to a lesser extent, however, the report discusses other contamination issues, such as bacterial and organic carbon loading, and as well provides background on existing biological communities and human activities for the Atlantic coast of Nova Scotia and offshore areas, that can be useful in putting environmental contamination in perspective.

The quality of measurements of contaminants is an important consideration in any study used as a basis for assessing the quality of the marine environment. Information comes from various sources — primary publications (results published in scientific journals, books and symposia); technical reports; consultants' reports — each of which have different standards and objectives, and reflect different levels of knowledge of the distribution and behaviour of contaminants in the environment. In the present study, information on measured levels of contaminants in the environment has been presented largely as it appears in the original publications, without any further critical evaluation. For example we have not included a discussion of changing sensitivity of chemical analysis techniques, methodology changes and possible errors, particularly in early studies, which may have led to erroneous measurements or conclusions. Further, we have not attempted to account for the effect of sediment type on measured contaminant levels, which tend to be higher in finer sediments; the different levels observed may then be a function of the type of bottom rather than the actual level of contamination in the environment. Generally, we have balanced our presentation by giving most weight to studies which either directly (by focusing on a specific sediment type, e.g. Loring *et al.* 1996) or indirectly (by sampling the same site periodically as in a monitoring study, e.g. Ernst *et al.* 1999) have taken sediment type differences into account. In addition to these concerns, the authors had some knowledge of the reliability of

much of the data or (in the case of consultants' studies) knew the reputation of the workers and the quality of the results, and have presented the data in (hopefully) a balanced way. Nonetheless, the bulk of the information came from primary publications or refereed technical reports. As is always the case, individuals using the information in this report should be aware of the particular requirements and limitations of the measurements they wish to use.

1.3 BACKGROUND AND REFERENCE LEVELS OF CONTAMINANTS

The objective in presenting information on contaminants on the Scotian Shelf is to provide a basis for an overall assessment of marine environmental quality (MEQ) or marine ecosystem health (MEH). MEQ has been defined as "the condition of a particular marine environment ....measured in relation to each of its intended uses and functions" (Wells *et al.* 1986; Wells and Côté 1988; Harding 1992). Marine ecosystem health (MEH) can be defined as "the maintenance of structure (types of species present, population size and composition) and function (movement of materials in the food web, energy sources) within the bounds of natural fluctuations." (Smiley *et al.* 1998). In practise, MEQ encompasses both these definitions.

Levels of contaminants in various environmental compartments give an indication of likely conditions impacting existing uses of the environment, and are a major category of indicators of marine ecosystem health (Harding 1992; Vandermeulen 1998; Smiley *et al.* 1998). In the inshore and offshore region of the Scotian Shelf, the main potential impacts of contaminants are to impair ecosystem function (and therefore ultimately to impact the sustainability of fisheries resources) and to make fisheries products unsuitable for consumption by humans when contamination in biological resources reaches significant levels. Another, though less important, issue is the question of tainting (introducing an off-taste) of resources (e.g. by hydrocarbons as a result of major petroleum spills) which reduces the marketability and results in an economic impact.

The degree of contamination of the marine environment (water, sediments and biota) may typically be determined by comparing concentrations to background levels or levels in uncontaminated reference areas; to levels known to be hazardous to aquatic organisms; and to levels in food species which pose human health concerns. Our approach is to present both the measured levels, as well as the various guideline and reference levels with which the levels in the environment can be compared. While other, more comprehensive, approaches to the assessment of environmental quality are available (such as looking at the integrity and extent of biological populations; impairment of human use etc., see Harding 1992; Wells and Rolston 1991), they are beyond the scope of the present document.

Various guidelines have been developed for 'safe' levels of contaminants in water sediments and biota (in particular food species) under Canadian law and various international standards. Examples are the current guidelines for levels of various important contaminants allowed to be deposited in the marine environment under Ocean Dumping provisions of the Canadian Environmental Protection Act (Table 1.1). In particular, the Canadian Environmental Quality Guidelines (CCME 1999) provide a set of guidelines for concentrations of a wide range of

contaminants in waters and marine sediments.[2] Guidelines are also available for determining safe levels of contaminants in food products. A number of such levels are presented in Tables 1.1 & 1.2. In this context, contaminants in food may include chemicals occurring naturally which may result in levels in food which are harmful to man; this is not, however, a problem on the Scotian Shelf.

Material	Regulated limit
Prohibited Substances [1]	
Cadmium	0.60 µg/g
Mercury	0.75 µg/g
Restricted Substances [2]	
Metals	
Arsenic	500 µg/g
Beryllium	1,000 µg/g
Chromium	1,000 µg/g
Copper	81 µg/g
Lead	66 µg/g
Nickel	1,000 µg/g
Vanadium	1,000 µg/g
Zinc	160 µg/g
Organics	
Chlorophenols	1.0 µg/g
PCBs	0.1 µg/g
PAHs	2.50 µg/g
Dioxins / furans	Any quantifiable 2,3,7,8 TCDD
Total oil and grease	10 µg/g

[1] Ocean dumping prohibited if levels exceeded.
[2] Levels which require passage of biological screening tests prior to dumping approval.

Table 1.1. Contaminants and regulated levels in sediments considered for ocean dumping under the Canadian Environmental Protection Act , 1995 (Environment Canada, Atlantic Region).

[2] The present report has not been updated to include comparisons of levels of contaminants with the current Canadian Environmental Quality Guidelines (CCME 1999). In most cases however the guidelines do not differ significantly from those available in 1996, and the initial interpretation is valid.

Table 1.2. Safe levels for contaminants in food (various sources) in 1996.

Substance	Concentration	Agency or Guideline
Trace Metals		
Arsenic	5 µg/g (fish tissue); 3.5 µg/g (fish protein)	Health and Welfare Canada Guidelines
Cadmium	400-500 µg/week	FAO (limit of human consumption)
	0.35 µg/g (fish tissue)	DFO Inspection Branch unofficial guideline (G. Burns, pers. comm.)
	0.2 µg/g (fish tissue); 2 µg/g (molluscs)	Acceptable level for shipment to Australia (Fisheries and Oceans Products Inspection Manual)
Copper	100 µg/g (marine and freshwater animal products)	Health and Welfare Canada Guidelines
	10 µg/g (fish tissue); 70 µg/g (molluscs).	Acceptable level for shipment to Australia (Fisheries and Oceans Products Inspection Manual)
Lead	0.5 µg/g (fish tissue)	Health and Welfare Canada Guidelines.
Mercury	0.5 µg/g (fish tissue)	Health and Welfare Canada Guidelines (from Eaton et al. 1986); acceptable level for shipment to Australia (DFO Products Inspection Manual).
Zinc	100 µg/g (fish tissue)	Health and Welfare Canada Guidelines.
	150 µg/g (fish tissue); 1,000 µg/g (oysters).	Acceptable level for shipment to Australia (DFO Products Inspection Manual).
Organic Contaminants		
PCBs	2 µg/g (fish tissue)	Health and Welfare Canada Guidelines
Dioxin	20 ng/g (fish tissue)	Health and Welfare Canada Guidelines

Comparison of measured levels of contaminants with levels of background or reference areas, is also used to determine marine environmental quality. Some background or otherwise significant levels of contaminants in the environment are presented below:

Water—Generally-accepted background levels for key metals in seawater are taken to be those found in offshore waters or waters of the Scotian Shelf (Ray and Bewers 1984). Levels of various contaminants in water that are hazardous to marine life, are summarized in McNeely *et al.* (1979). The Canadian Drinking Water Guidelines (CCREM 1987) have also been used in some cases to give an indication of the relative elevation of contaminant levels found in marine waters.

Sediments—Only Loring *et al.*'s (1996) survey of sediments in coastal inlets (including some relatively undeveloped ones) provides a detailed assessment of background levels of metals in Nova Scotia Atlantic coastal sediments (Table 1.3). In addition, current Canadian interim sediment quality guidelines for contaminants in marine sediments include levels of concern for metals and organic contaminants (Environment Canada 1995; CCME 1999).

Metal	Concentration (ug/g)/ dry weight
Arsenic	20 ug/g
Cadmium	0.3 ug/g
Copper	40 ug/g
Mercury	0.1 ug/g
Lead	40 ug/g
Tin	5 ug/g
Zinc	150 ug/g

Table 1.3. Natural background levels of trace metals in sediments around the world. From Loring *et al.* 1996.

In addition to published background levels or guidelines, levels of some contaminants measured in 'clean' areas of the Atlantic coast can serve as indicators of relative levels of contamination. Levels of petroleum hydrocarbons in such areas may be found in studies of sediments in offshore (Keizer *et al.* 1978b) and coastal (Hargrave and Phillips 1975) areas of the Nova Scotia Atlantic coast, and in a range of area harbours (Levy *et al.* 1988).

Levels of total PAHs in sediments at eleven 'uncontaminated' sites along the Eastern Shore of Nova Scotia in 1983 (Hildebrand 1984 from O'Neill and Kieley 1992) ranged from not detectable to 0.53 μg/g dry weight. In the absence of other information, this level can probably be considered an acceptable background. PAH levels are excessive when they are greater than 2 μg/g (Gearing *et al.* 1994), and sediments having levels of 2.5 μg/g PAH require further screening before ocean disposal.

Low background levels of PCBs (absent or below 10 ng/g) have been found at a number of 'control' sites away from coastal development in Southwest Nova Scotia (Yarmouth to Port LaTour) (Wiltshire 1978), and levels below 5 ng/g were found at five coastal sites on the Nova Scotia Eastern Shore (Leonard 1977). The generally-accepted background level for PCBs in the Gulf of St. Lawrence is 0.1 ng/g (Gilbert and Walsh 1996). PCBs are synthetic chemicals, and the presence of any in sediments indicates contamination. Acceptable levels for ocean dumping are 100 ng/g, while interim Canadian sediment quality guidelines give 21.5 ng/g as an acceptable level (Environment Canada 1995; CCME 1999). Measurements of PCBs and DDT made in the 1970s may be suspect due to methodology used.

Sediments from eight coastal sites on the Eastern Shore east of Halifax and at Clark's Harbour, had concentrations of DDT and congeners generally below 1 ng/g, but ranging up to 20 ng/g (Leonard 1977). A similar level of total DDT (17 ng/g) was detected in shelf sediments off the coast in the approaches to Chedabucto Bay (Martec Limited (1984), see Section 3.5), indicating that the compounds may be fairly ubiquitous in the marine environment. Some of these levels are above the interim Canadian sediment quality guideline for total DDT of 3.89 ng/g (Environment Canada 1995); however 1 ng/g can be considered a background level for our purposes.

Comparison of contaminant concentrations in sediments between coastal areas is difficult because of differing sampling and analytical techniques, as well as different sedimentary properties (e.g. texture). In practise, we have not differentiated between sampling methods and grain size in evaluating contaminant levels.

Biota— Background levels of contaminants in biological organisms determined from various studies, as well as guidelines for safe levels of contaminants in marine fish and shellfish consumed by humans, have in general been used for our comparisons. In addition, average concentrations of contaminants in mussels for United States coastal areas in 'Mussel Watch' programs (O'Connor 1992), and Canadian and American food quality guidelines for particular contaminants in mussel tissue (Table 1.4), are available to allow assessment of levels of contamination.

Background levels of contaminants have been determined principally for lobster and blue mussels, and occasionally for major fisheries species, usually from 'control' samples to support studies evaluating major contaminant problems or concerns (e.g. PAH contamination of Sydney harbour; major oil spills; cadmium or PCB contamination of fish and fish products, etc.); and in monitoring studies to identify potential contamination problems (Environment Canada & Zenon Environmental Inc. 1989MS).

Background PAH levels in the digestive glands of lobster from 'control' areas have been measured to be from 68 to 832 ng/g (Scarratt 1980; Sirota and Uthe 1980; Sirota *et al.* 1983 & 1984). Many levels in lobster from coastal areas are less than 750 ng/g (Figure 1.2). All measurements of PAHs in lobster have been made in coastal areas, and so are probably elevated over levels likely to be found in so-called 'pristine' environments. Lobster move widely in coastal areas as adults, and may encounter water and sediments contaminated with petroleum hydrocarbons and creosote from preserved timber on wharves, which are potential sources of contamination.

Cadmium concentration in lobster (measured in the digestive gland) on the Atlantic coast of Nova Scotia was assessed in the 1970s because of concern over levels in lobster paste (Uthe and Freeman 1980). Averages, ranging from 5.2 to 13.3 μg/g wet weight (maximum in any lobster of 53 μg/g wet weight) are used for comparisons (Table 1.5). Arsenic levels in lobster in several coastal areas of the eastern shore of Nova Scotia (Table 1.5) probably represent naturally-occurring values. Further discussion of cadmium and arsenic in lobster is presented in Section 3.2.2.

Concentrations of contaminants in mussels have been measured occasionally and are used increasingly as a measure of environmental quality. Environment Canada measured a wide range of contaminants in mussels at a control site (Beaver Harbour) in 1989 (Zenon Environmental Inc. 1989MS), while background PAH levels (from 6 - 77 ng/g wet weight of tissue) were measured in mussels from Larry's River and Havre Boucher in 1979 (Scarratt 1980). These have been used in comparisons. Since measurements in mussels often have been expressed either in terms of dry or wet weight of tissue, wet weight concentrations in mussels can be converted to those based on dry weight for comparison by using a factor of 6.7 (GMCME 1994).

Health and Welfare Canada has established acceptable levels of various contaminants in fish and fish products; these levels and those for products shipped to other countries are used for fish product inspection (Table 1.2), and are occasionally used for comparison here. Health Canada, Canadian Food Inspection Agency, routinely monitors commercial catch to ensure that levels of contaminants meet food quality standards, and these levels (although not compiled here) thus represent an upper limit of levels normally encountered. The Canadian Shellfish Sanitation Program also has guidelines for contaminant levels in shellfish (CSSP 1992, see Table 1.4). United States Food and Drug Administration guidelines for several metals in mollusc tissue have also occasionally been used (USFDA 1990, 1993; Table 1.4).

Table 1.4. Background and comparative levels of contaminants in blue mussels (*Mytilus edulis*).

	Concentration in Tissue (based on dry weight unless specified)			
	Undeveloped Nova Scotia Site (Beaver Harbour, 1989) [1]	United States Coastal Areas (yearly geometric averages, 1986-1990) [3]	Gulf of Maine (1992), arithmetic average [4]	Acceptable Level for Human Consumption [7]
Metals				
Arsenic	1.6 ug/g [2]	8.7 - 10.0 [6]		
Cadmium	2.1 ug/g [2]	1.2 - 5.9 ug/g [5]	1.8 ug/g	25 ug/g
Chromium	0.48 ug/g [2]	1.5 - 1.9 ug/g	1.5 ug/g	87 ug/g
Copper	1.2 ug/g [2]	9.0 - 9.9 ug/g		
Mercury	0.064 ug/g [2]	0.1 ug/g [6]	0.12 ug/g	6.7 ug/g
Lead	< 0.5 ug/g [2]	1.5 - 2 ug/g	2.6 ug/g	11.5 ug/g
Nickel	0.57 ug/g [2]		1.8 ug/g	533 ug/g
Silver	< 0.3 ug/g [2]	0.2 ug/g	0.12 ug/g	
Zinc	11 ug/g [2]	120 - 140 ug/g	89 ug/g	
Organic Compounds				
DDT Total		35 - 47 ng/g		33 ug/g
PAH Total		230 - 300 ng/g		
PCB Total		110 - 180 ng/g		13 ug/g
Butyltin total		80 - 130 ng/g		

1. Zenon Environmental Inc. 1989 MS.
2. wet weight--to convert to estimate on dry weight basis, multiply by 6.7 (GMCME 1994).
3. O'Connor (1992).
4. Gulf of Maine Council on the Marine Environment (1994).
5. Long Island Sound (O'Connor 1992).
6. Levels in oysters and mussels.
7. CSSP 1992; USFDA 1990, 1993.

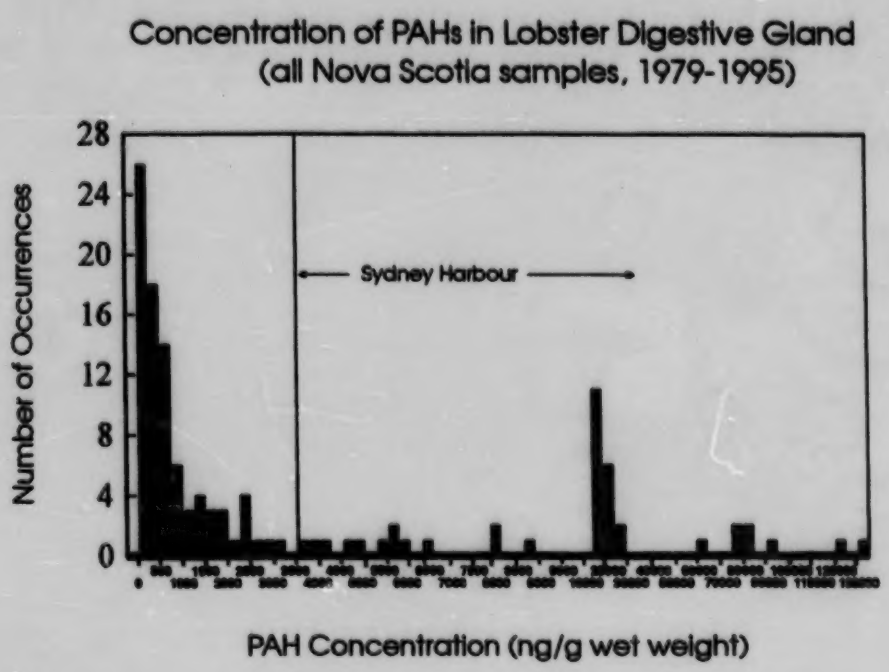


Figure 1.2. Total polycyclic aromatic hydrocarbon (PAH) concentration in lobster (*Homarus americanus*) digestive glands from studies on the Atlantic coast of Nova Scotia, 1979-1995 (Sirota *et al.* 1983 & 1984; Sirota and Uthe 1980; Scarratt 1980; Uthe and Musial 1986; Uthe *et al.* 1989; JWEL-IT Joint Venture 1996).

Table 1.5. Cadmium and arsenic concentration in digestive glands of lobster (*Homarus americanus*) from Atlantic coastal areas of Nova Scotia. From Uthe and Freeman (1980) except where indicated.

Location	Cadmium Concentration (ug/g wet weight) and range	Arsenic Concentration (ug/g wet weight)
Arichat	7.87 (3.22 - 19.6)	10.56 [2]
Dingwall	13.30 (5.14 - 27.4)	–
Frambois	12.51 (4.05 - 52.9)	–
Halifax [1]	8.59 (4.64 - 15.1)	–
La Have	8.15 (2.94 - 15.4)	–
Larry's River	8.27 (3.92 - 25.1)	–
Liverpool	5.19 (1.33 - 16.7)	–
Lockeport	7.38 (2.80 - 22.4)	–
Main-a-Dieu	12.58 (4.89 - 47.2)	8.71 [2]
Pubnico	10.42 (5.18 - 21.4)	–
Sambro	8.03 (2.0 - 18.0)	16.20 [2]
Tangier	6.15 (2.4 - 20.0)	11.54 [2]

[1] Chou and Uthe (1978)
[2] Freeman and Uthe (1974)

1.4 SOURCES OF CONTAMINANTS

1.4.1 Introduction

A wide range of human activities in the coastal zone and in offshore areas, as well as some which take place inland, have the potential to release contaminants into the marine environment. The following discussion focuses briefly on sources or issues which are of particular relevance to the Scotian Shelf and adjacent coastal areas. A thorough discussion of potential sources of contaminants and impacts on the marine environment of the Atlantic region and the world oceans in general are presented in Wells and Rolston (1991) and UNEP (1995), while other good sources for information on sources include Eaton *et al.* (1986); Wilson and Addison (1984); and Eaton *et al.* (1994).

Inshore and offshore areas are influenced by different sources of marine contaminants released by human activities. In offshore waters, contaminants are deposited primarily by atmospheric processes and as the result of mixing with coastal waters. The atmosphere carries particulate soot, dust, aerosols, and gases, and associated trace metals, organic compounds such as polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs), radioactive materials and microorganisms (Brandon and Yeats 1984; Ware and Addison 1973 from Wells and Rolston 1991; Hilborn and Still 1990). Rivers and streams flowing off the landmass of Nova Scotia carry dissolved and suspended chemicals into the ocean. Table 1.6 shows the relative importance of three sources of trace metals onto the Scotian Shelf—precipitation, rivers, and outflow of the Gulf of St. Lawrence through the Cabot Strait. The outflow of the Gulf of St. Lawrence, with its large component of St. Lawrence River water, is one of the major influences on the characteristics of the surface waters of the Scotian Shelf, and is also one of the major sources of contaminants, both anthropogenic and natural, which derive from its large drainage area. During their transfer from a source to a final repository (which may be coastal sediments, basins on the continental shelf, or the deep sea), contaminants may be diluted, chemically transformed, or partitioned into chemical and biological phases.

Table 1.6. Estimated inputs of trace metals to the Scotian Shelf (from Dr. P. Yeats, DFO, personal communication).

	Input (tonnes/yr)		
Metal	Precipitation	River	Gulf of St. Lawrence
Cadmium	2.6	0.76	28
Copper	29	110	2,400
Lead	44	11	160
Manganese	88	1,400	9,200
Nickel	13	12	3,300
Vanadium	73	10	14,000
Zinc	120	110	4,700

Human inputs of chemicals also occur in offshore areas, consisting of releases such as hydrocarbons from accidental and routine discharges from tankers, shipping accidents, passage of ships and fishing vessels, incidental wastes from hydrocarbon drilling and production activities, and persistent litter from local and distant sources. An additional minor source of contaminants is the burden found in tissues of migratory organisms (the fish, birds and marine mammals such as seals and whales) which live in the area for part of the year and which may transport these substances from other areas.

In coastal areas, where most of the population resides and industrial development occurs, many chemicals can enter the marine environment directly. Typical inputs of contaminants to the marine environment in coastal areas include: municipal effluents containing high levels of organic matter and various hazardous chemicals from both domestic and industrial sources as well as runoff; direct industrial input from major industries including pulp and paper, food and fish processing, refineries, smelters, hydrocarbon and mineral handling and transfer facilities, and public utilities such as thermal electric generating plants (Wells and Rolston 1991). Coastal areas receive, as well, contaminants in river flow and from various non-point sources of pollution—agriculture and forest sprays; chemicals used in brush control; atmospheric deposition; and urban runoff—containing measurable levels of hydrocarbons, metals, silt and persistent plastics entering waters near cities, towns and industrial sites. A number of other human activities impact coastal waters by adding organic matter from human sewage or fish processing wastes; human pathogens; and nutrients, essential elements such as iron, and other chemicals which stimulate plant productivity and may create conditions leading to increased incidence of toxic algal blooms.

In addition to these sources, some activities in coastal areas can redistribute contaminants, including: bottom trawling for fisheries species; seabed mining; construction of coastal facilities; and dredging and ocean disposal of dredge materials. Trawling and dragging in commercial fisheries increases near-bottom suspended sediment concentrations, and mixes surface and subsurface layers of sediments (Mayer *et al.* 1991; Messieh *et al.* 1991). Mining the seabed for sand to manufacture glass for optic fibres, or for extraction of minerals (e.g. gold in placer deposits, construction aggregate), have been proposed for Atlantic coastal areas, and may in future take place. Seabed mining would typically lead to elevations in suspended particulate material in the water column and potentially result in release of contaminants found in the sediments.

1.4.2 Natural Sources of Contaminants

Substances defined as contaminants may enter the ocean through natural processes, principally weathering of the continents, coastal rock and seabed. These materials reach the ocean in surface runoff; suspended in the atmosphere as dust; dissolved in groundwater; or released from the sediments after chemical change or diagenesis.

The chemistry of the ocean and its sediments is determined by the long-term weathering of the continents; the subsequent redistribution and modification of the dissolved and particulate material by physical, chemical and biological processes; and the continuous interaction of the sea with the atmosphere, coastal and offshore rock, sands, muds and biota. Waters dissolve and capture gaseous and particulate contaminants from the air, and leach materials from the sediments, both from exposed surfaces and when they penetrate them as pore waters. Biological organisms influence the concentration and distribution of chemicals, in the case of phytoplankton, by utilizing trace chemicals and distributing them through the water column, and in seabed animals which disturb the sediments and pump water through them, enhancing chemical exchange (e.g. Boudreau and Marinelli 1994). The involvement of sediments in transfers is influenced by the types of seabed material available. Much of the offshore seabed of the Scotian Shelf—which is a remnant of glacial deposits and includes extensive areas of sand-

gravel mixtures on banks and edges, and areas of silts and clays in offshore basins (King and Fader 1986) (Figures 1.3 and 1.4)—may be expected to influence water chemistry in characteristic ways.

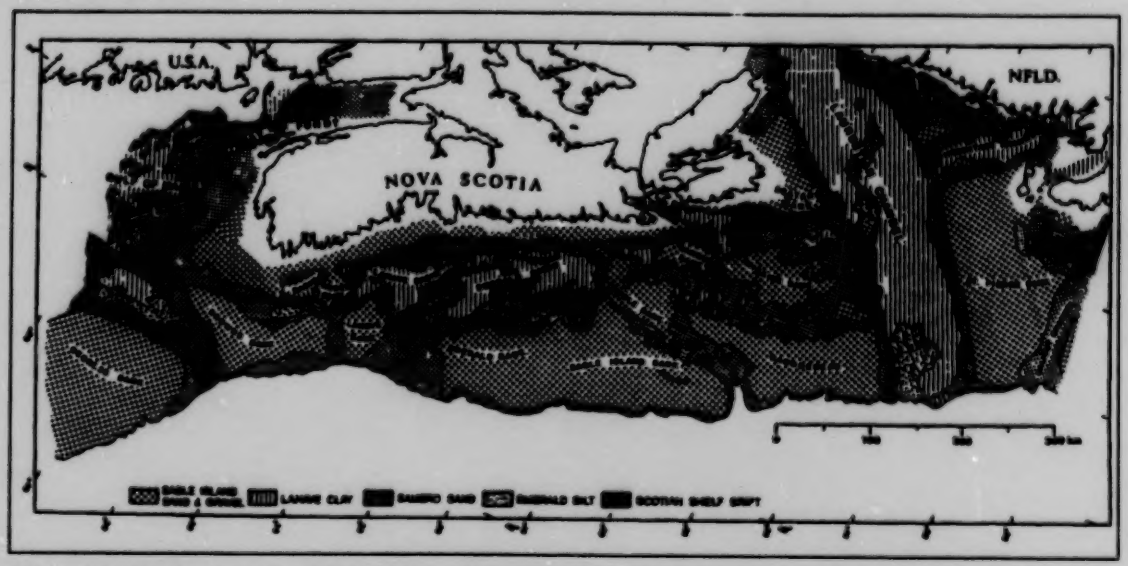


Figure 1.3. Distribution of surficial sediment formations from the Bay of Fundy, Gulf of Maine, Scotian Shelf, Laurentian Channel and the western Grand Banks of Newfoundland (King & Fader 1986).

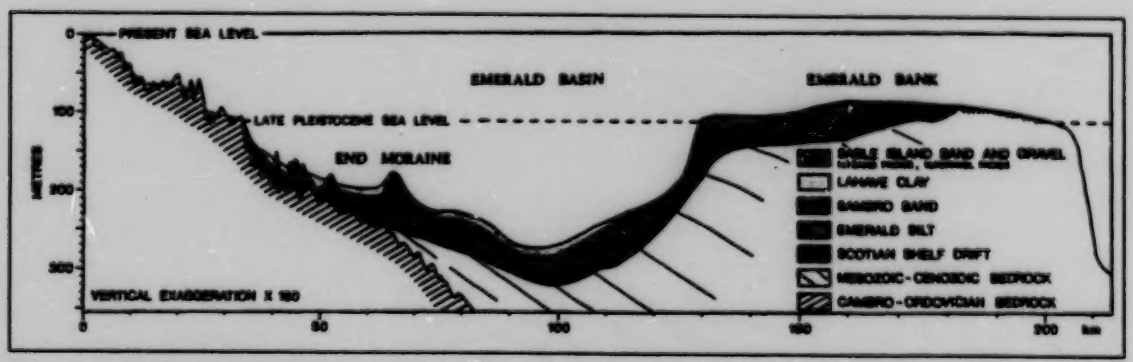


Figure 1.4. Diagrammatic cross-section of the Scotian Shelf across Emerald Basin and Emerald Bank showing the distribution and relationships among surficial sediment formations, bedrock, and the last low sea level position (King & Fader 1986).

Locally, these normally-occurring processes can sometimes cause levels of chemicals to occur that are above usually accepted background or so-called 'natural' values. This is the case, for example, for natural petroleum seeps. Although no reports of seeps of hydrocarbons on the Scotian Shelf have been made, some areas of clay sediments in basins on the Scotian Shelf have features known as pockmarks which have been interpreted as being caused by releases of gas or water from the seabed (King and MacLean 1970). Another example is the concentration of

manganese in suspended matter, which occurs at elevated levels above the bottom in deep basins on the Scotian Shelf, the result of chemical interactions with sediments.

Freshwater inflows having naturally elevated concentrations of substances such as mercury and arsenic, and other processes can also lead to naturally-elevated concentrations of various metals (e.g. manganese), while organic contaminants, principally polycyclic aromatic hydrocarbons (PAHs) from forest fires, can be important inputs to the ocean, particularly in inshore areas (Blumer *et al.* 1977 from Keizer *et al.* 1978a).

1.4.3 Anthropogenic Sources

Overview

Prior to the modern environmental era and the advent of a Canadian legal framework for managing human inputs of chemicals and other deleterious substances to the marine environment, the sea was regarded as a convenient site for disposal of the majority of wastes produced from industries and the human population of coastal areas. Laws and regulations now limit the production and entry of most key chemical contaminants (e.g. polychlorinated biphenyls, PCBs; dioxins, furans and mercury in the pulp and paper industry; and pesticides such as DDT and Mirex, among others), into the environment. The earlier environmental practises, however, resulted in, and still cause, severe contamination of coastal marine areas, in many cases which has yet to be remedied (e.g. Sydney and Halifax Harbours).

Coastal areas adjoining the Scotian Shelf have been exposed typically to various contaminant sources, including: urban contamination (domestic sewage, contaminated runoff, dust and airborne emissions, litter, domestic toxic chemicals, small industry and manufacturing outputs, and releases related to shipping and marine vessel repair); and releases from a few large industries (pulp and paper mills, coal mining and benefaction operations, residual inputs from former mining activities (e.g. some coastal waters are exposed to elevated concentrations of arsenic resulting from past gold-mining activity), refineries and steel mills) (Figure 1.5) (Table 1.7). The fishing industry and associated infrastructure (wharves and harbours, vessel maintenance and repair facilities, and fish processing operations) is a source principally of organic contamination (e.g. fish plant wastes), hydrocarbon releases from fuels and lubricants, and anti-fouling and wood preservative chemicals (e.g. tributyltin oxide and creosote). Atlantic coastal areas and watersheds of Nova Scotia are predominantly forested and so releases of chemicals typically associated with agriculture, such as pesticides and herbicides, are not important, compared with areas where agriculture is more prevalent. Releases of contaminants derived from the widespread combustion of fuels (in particular fossil fuels), particularly in heavy industry and thermal power generation, has also added significant additional loads of organic contaminants (such as PAHs) to the marine environment. A wide range of contaminants from more industrialized parts of eastern North America reach the Scotian Shelf by atmospheric transport. Although the majority of these sources, characteristic of a 20th century society, are present in Nova Scotia, the province is not highly industrialized in relative terms, and its population is low and concentrated in a few large centres located mainly in coastal areas.

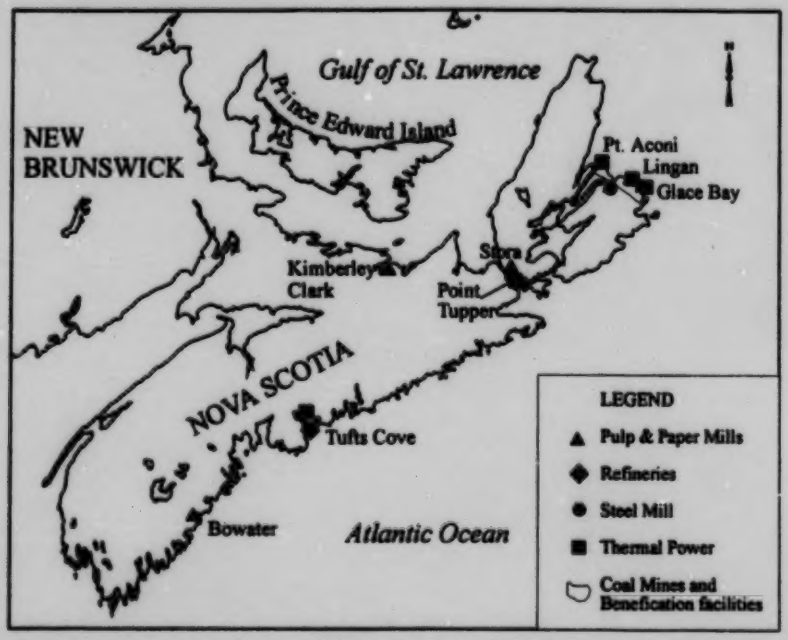


Figure 1.5. Location of major industries and industrial activities on the Atlantic Coast of Nova Scotia (Sources: Eaton *et al.* 1986; Swiss 1984).

Releases of contaminants in coastal areas probably influence levels in offshore waters of the Scotian Shelf. Compared to local sources, however, chemicals in the outflow of the Gulf of St. Lawrence (which arises in the industrialized areas of Canada and the U.S. that lie in the Great Lakes drainage basin) and atmospheric influences, probably outweigh any local sources of most contaminants to the Scotian Shelf. An exception is hydrocarbons, for which comprehensive studies of contaminants in the marine environment of the Scotian Shelf have been carried out. In the early 1980s, levels of petroleum hydrocarbons on the Scotian Shelf and Cabot Strait were elevated over those in the Gulf of St. Lawrence (Levy 1984).

Table 1.7. Pollution sources in coastal and offshore areas of the Atlantic Coast of Nova Scotia (from Wells and Rolston (1991) and Eaton *et al.* (1986)).

Source	Nature of Contaminant / Impact
Municipal Effluents	Shellfish and aquaculture closure due to bacterial contamination. Enrichment of sediment organic content near outfalls and seepages. Contamination of sediments and waters by metals and organic chemicals (e.g. PCBs and hydrocarbons). Nutrient enrichment of coastal waters.
Dredging and Ocean Dumping	Contaminants occurring at concentrations below Ocean Dumping limits in sediments, including PAHs, PCBs, trace metals, organic matter, oil and grease.
Wharves and Coastal Structures and Associated Activities	Metals and organic compounds in paints; creosote and preservatives (e.g. Wolmanized lumber, chromated copper arsenate) on wharf pilings.
Aquaculture (Fish and Shellfish farming)	Organic matter, trace metal enrichment.
Industrial Effluents	
Pulp and Paper	Wood fibre, suspended solids, effluents having high biological oxygen demand (BOD) and contaminants (e.g. dioxins and furans).
Food Processing (including Fish processing)	Effluents high in BOD, suspended solids, oil and grease, bacteria and organic and inorganic contaminants.
Petroleum refining	Oil and grease, sulfide, amnonia, phenol, suspended solids, and PAHs.
Smelters and Steel Industry	PAHs and other organic chemicals; metals.
Thermal Generating Plants	PAHs from coal ash and leachates (including coal tar and creosote). PAHs and metals from atmospheric deposition.
Shipyards and Vessel Maintenace Facilities	Organics, metals, antifouling chemicals (e.g. tributyltin, lead).
Mining and Associated Industries	Acid mine drainage, metals, organics, waste rock; arsenic from gold mining tailings.
Hydrocarbon storage, shipment, and distribution	Hydrocarbons account for most of accidental spillages of chemicals in Atlantic Canada.

In general, controls imposed on industrial effluents and regulation of use of chemicals known to be toxic, both in Canada and the U.S., have reduced the most significant loads of toxic and harmful chemicals to the Scotian Shelf from all these sources over the last 20 years. Nonetheless, industrial inputs to coastal waters have been major contributors to contamination in coastal areas. Good overviews of industrial contamination in the Atlantic Region are provided in other reports (Eaton *et al.* 1994; Wells and Rolston 1991). Some of the other important issues and problems in contamination of the Scotian Shelf are presented in the following sections.

Organic Enrichment of Coastal Sediments

Various sources of organic matter (compounds based on naturally occurring carbon compounds from biological organisms) lead to local enrichment in coastal marine environments. Domestic sewage enters the coastal marine environment from residential, municipal and industrial sources.

Typically it has elevated levels of organic matter, nutrients and bacterial counts, as well as containing significant and variable amounts of various contaminants. Particulate organic matter in the waste stream frequently settles near the outfall, leading to localized organic enrichment in sediments and to reductions in oxygenation, both in sediments and adjacent waters, while associated nutrients can lead to elevated productivity of algae (eutrophication), resulting in further enhancement of local levels of organic matter. Reduced oxygen concentration in water resulting from biological oxygen demand of the effluents can cause local reductions or removal of communities of marine organisms, and result in chemical changes leading to elevated concentrations of metals. Elevated levels of contaminants such as metals in the effluent also contribute to 'hot spots' of metal contamination found around raw sewage sources, such as occur in Halifax Inlet (See Section 3.3.4 and Figure 3.12).

Food processing facilities produce effluents having an elevated organic content and consequent high biological oxygen demand. Along the Atlantic Coast of Nova Scotia, fish processing is the commonest of these sources. Although fish plant effluents are regulated and impacts are typically localized, seabed environments in the vicinity of plants frequently have elevated levels of organic matter in sediments, and high biological oxygen demand, while areas along wharves are often contaminated with organic debris resulting from disposal of waste fish and offal over the side from fishing vessels and deck cleaning. In these areas elevated organic concentration and reduced oxygen can lead to development of bacterial mats (e.g. *Beggiatoa* sp) on the seabed.

Effluents from the pulp and paper industry typically have elevated contents of particulate organic matter in the form of wood fibre and fine particulates, and dissolved organic compounds including resins and fatty acids, as well as various additional contaminants (e.g. mercury, dioxins, furans, chlorine and chlorine compounds), both from past and present operations. Environmental regulations applying to effluents in these industries introduced over the past two decades, have resulted in significant improvements in the quality of effluents (Wells and Rolston 1991; Eaton *et al.* 1986; Eaton *et al.* 1994). Nonetheless, wood fibre and waste debris accumulations occur on the seabed near two existing pulp and paper facilities on the Atlantic coast of Nova Scotia, the result of accumulations from releases which took place before effective regulation was in place. The deposits are poorly oxygenated and have an unsuitable texture, together limiting the occurrence of normal biological communities, and often showing development of *Beggiatoa* typical of other areas having anoxic sediments. Examples of wood fibre accumulations are Liverpool Bay and Harbour (Section 3.7) and the Strait of Canso (Section 3.5.4), and are described in Scarratt and Associates (1994 a & b) and Buckley *et al.* (1974).

Fecal Coliform Contamination

Many areas on the Atlantic coast of Nova Scotia receive untreated sewage from coastal communities and residential/cottage development. In addition to a significant content of organic matter, nutrients and contaminants, these discharges constitute a public health risk because of their potential for carrying human pathogenic bacteria, as well as normal gut bacteria (*Escherichia coli*) which can be harmful in certain circumstances. Levels of coliform bacteria (of which *E. coli* is a representative) are used as an indicator of risk in coastal waters. Human activities can be impacted if levels of coliform bacteria reach certain thresholds (e.g. swimming

is not permitted at levels of 200 counts/100mL (CCREM 1987)), while harvesting and consumption of shellfish is prohibited when counts reach regulated levels, established under the Canadian Shellfish Sanitation Program (CSSP) or because an area is close to industrial or municipal discharges (CSSP 1992; Menon 1988). Harvesting of shellfish is not permitted when levels of fecal coliform bacteria in water reach 14 counts/100 mL (most probable number method) or if more than 10% of the samples exceed 43 counts/100 mL (Menon 1988). Aquaculture operations cannot be established in areas closed to shellfish harvesting.

The Nova Scotia Atlantic coast is comparatively free of coliform contamination except for the Sydney Harbour-Glace Bay area and Halifax Harbour (Machell and Menon 1992). In 1992, three of ten shellfish-growing areas on the coast had more area closed than permitted for shellfish harvesting (Figures 1.6 & 1.7). The amount of coastal area closed to shellfish harvesting increased by approximately 34 km^2 per year in the 1989 to 1992 period.

Toxic Phytoplankton

Widespread human modification of coastal marine environments is believed to have resulted in worldwide increases in the incidence of toxic phytoplankton blooms (Bates and Worms 1989). The Scotian Shelf and coastal areas along the Atlantic coast of Nova Scotia, however, have not exhibited significant incidence of various types of poisoning found elsewhere in Eastern Canada, although recent monitoring programs have shown that most of the causative organisms occur here (Bugden *et al.* 1992; Keizer *et al.* 1996) (Figure 1.8; Table 1.8).

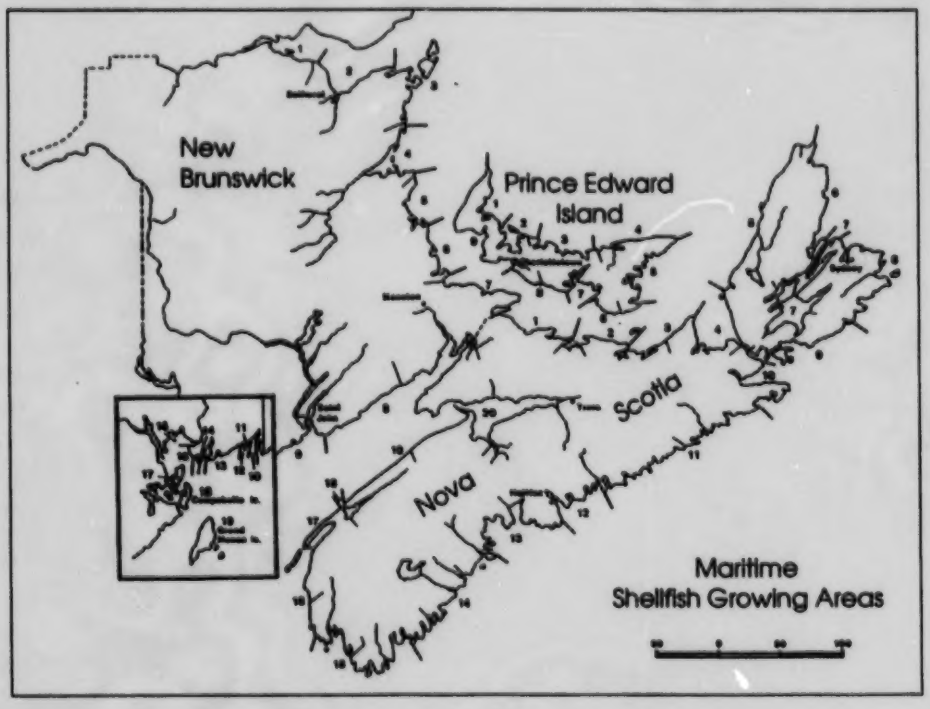


Figure 1.6. Maritime shellfish growing areas (from Machell and Menon 1992).

For example, no poisoning incidents have been reported for Paralytic Shellfish Poisoning (PSP) (normally caused by the dinoflagellate *Alexandrium fundyense* and *A. excavatum*), or Amnesic Shellfish Poisoning (ASP), caused by the diatom *Nitzschia pseudodelicatissima* (Stewart 1994) (Table 1.8), while only isolated and mild Diarrhetic Shellfish Poisoning (DSP) incidents have been reported from the Atlantic coast of Nova Scotia. PSP toxins have not been reported in sea scallops from the Scotian Shelf, although they have been detected on Georges Bank (Martin *et al.* 1992; Gillis *et al.* 1991).

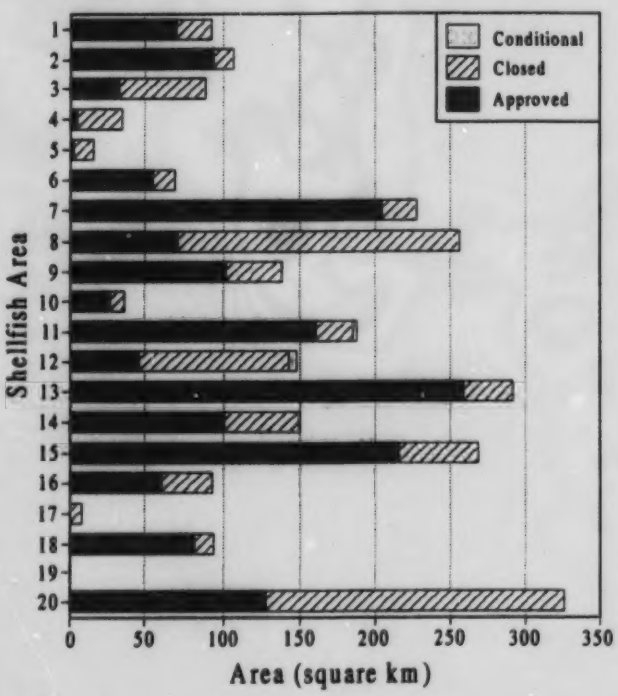


Figure 1.7. Classification of shellfish areas for Nova Scotia (from Machell and Menon 1992). For locations see Figure 1.6.

Table 1.8. List of potentially toxic or harmful phytoplankton species detected at monitoring stations on the Atlantic Coast of Nova Scotia (from Bugden *et al.* 1992, Figure 1.8).

Location	Species
Woods Harbour	*Alexandrium* spp, *Dinophysis* spp, *Prorocentrum* spp, *Nitzschia pungens* forma *multiseries* [1]
St. Margaret's Bay	*Alexandrium* spp, *Dinophysis* spp., *Prorocentrum* spp, *Nitzschia pungens* forma *multiseries* [1], *Nitzschia pseudodelicatissima* [2], *Chaetoceros concavicornis*
Ship Harbour	*Dinophysis* spp, *Prorocentrum* spp, *Nitzschia pungens* forma *multiseries* [1], *Nitzschia pseudodelicatissima* [2]
Tor Bay	*Dinophysis* spp, *Prorocentrum* spp, *Nitzschia pungens* forma *multiseries* [1], *Nitzschia pseudodelicatissima* [2]

[1] Present name, *Pseudonitzschia multiseries* (S. Bates, DFO, personal communication).
[2] Present name, *Pseudonitzschia delicatissima* (S. Bates, DFO, personal communication).

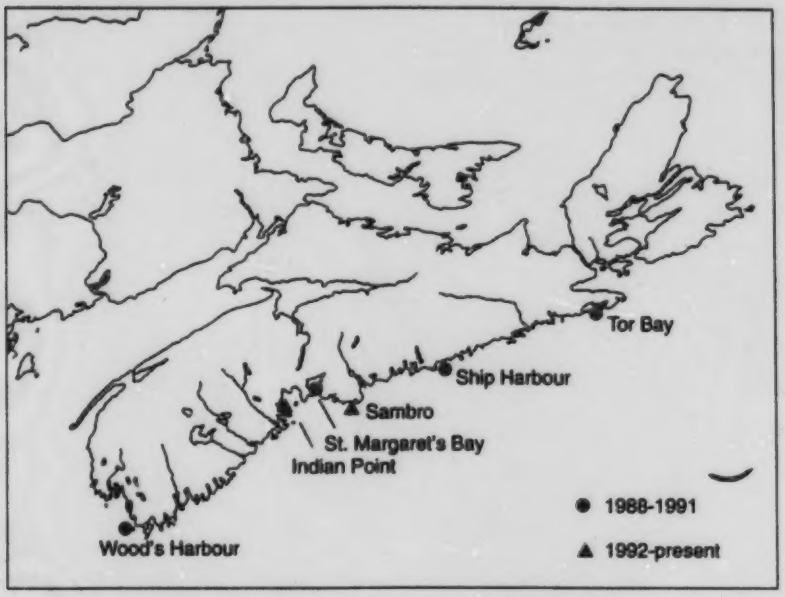


Figure 1.8. Location of stations for Fisheries and Oceans Canada monitoring of toxic phytoplankton on the Atlantic Coast of Nova Scotia (Budgen *et al* 1992; Keizer *et al* 1996).

Persistent Marine Litter

Persistent marine litter occurs on the Scotian Shelf as it does in most areas of the world's oceans. There is an increasing awareness of the impact of litter on marine organisms, which includes entrapping and entangling marine mammals and seabirds and 'ghost fishing' by abandoned or damaged fishing nets; or causing death when various forms of litter are ingested. Litter is also an indicator of more serious contamination problems by humans. Items constructed of plastic occur most commonly worldwide (Eaton 1984) and in Scotian Shelf and Atlantic coastal waters (Lucas 1992; Dufault and Whitehead 1994; Clean Nova Scotia Foundation 1995MS), accounting for 92% of items on Sable Island and along the Atlantic Coast (Tables 1.9 & 1.10). Up to 8 kg per kilometre per month washed up on the beaches of Sable Island from 1984 to 1986. Concentrations of plastic pellets or 'nibs' on Sable Island were low compared with those reported from other beaches in the world (Lucas 1992). Dufault and Whitehead (1994) found greater concentrations of large debris (visible floating items) and lower concentrations of smaller debris (captured in a fine-meshed, 0.308 mm net) than reported in the literature for other areas of the world.

Table 1.9. Categories of persistent litter found at Sable Island in 1984-1986 (from Lucas 1992).

Litter Type	Average number of items per kilometre per month				Percentage of Total
	1984	1985	1986	Average	
Fishing Equipment Polypropylene Net	33	21	23	26	12.0
Miscellaneous	1	2	1	1	0.8
Polypropylene Rope	50	26	35	37	16.1
Plastic Items	184	126	108	139	63.8
Glass Items	16	15	10	14	6.2
Metal Items	3	2	2	2	1.1
Total	**287**	**192**	**179**	**219**	**100.0**

Table 1.10. Types of marine litter found on Sable Island (1984-86) and in open water on the Scotian Shelf (1990) (from Lucas (1992) and Dufault and Whitehead (1994)).

Sable Island (Lucas 1992)	Outer Scotian Shelf (Dufault and Whitehead 1994)
Tampon dispensers	**LARGE ITEMS**
Polystyrene cups	Plastic grocery bags
Polystyrene packing materials	Nylon rope
Plastic containers for food, oil and cleansers	Potato chip bags
Polyethylene bags and sheet	Styrofoam
Liquor and soft drink bottles	Food container lid
Fluorescent tubes	**SMALL ITEMS**
Incandescent bulbs	White styrofoam pieces
Plastic strapping	Textile fibres
Polypropylene rope	Fishing Line
Fishing equipment	Cellophane
	Hard plastic pieces

Shipping

Shipping is a major source of hydrocarbons and other anthropogenic contaminants to the ocean worldwide, and provides important inputs to the Scotian Shelf. Associated with ship traffic are incidental and accidental releases of hydrocarbons from tank and ballast water clearing and bilge operations; releases of metals from sacrificial anodes (plates of metals such as lead and zinc which corrode preferentially in seawater and leave other ship metal intact) and antifouling paints; marine litter and garbage disposal from routine disposal practises; and spills of fuel, chemicals, and ship debris and cargoes from ship accidents. Accidental releases of hydrocarbons from vessel and tanker traffic account for more hydrocarbons reaching the marine environment than

the occasional major oil spills (Levy 1984). Levels of hydrocarbons and persistent marine litter found on the Scotian Shelf, however, are minor by world standards, reflecting the lower level of marine vessel traffic compared with other areas (Wells and Rolston 1991).

Fishing Activity

Although there is increasing awareness that some forms of fishing may have significant destructive effects on biological communities and the seabed, the fishing industry does not contribute significantly to contaminant levels on the Scotian Shelf. Minor contaminant sources include the use of the wood preservative tri-butyltin oxide on lobster gear, and on nets by the aquaculture industry (prohibited in the late 1980s, Kieley 1989), and the use of creosote prior to the mid-1980s as a wood preservative in lobster pounds. Before the practise was discontinued, polycyclic aromatic hydrocarbons (PAHs) from the use of creosote were found in impounded lobster (Uthe *et al.* 1984). Creosoted timbers on new or existing wharves are a significant source of PAHs to the coastal marine environment. Elevated loading of the seabed with organic carbon from wastes can occur in coastal shellfish aquaculture operations (Grant *et al.* 1995) but is not a significant concern; while finfish aquaculture in coastal waters can result in enrichments of both organic matter and zinc in sediments from unused food and feces (G. Winters, Fisheries and Oceans Canada, personal communication). In early 1996, some 70 licenses had been issued for aquaculture operations on the Nova Scotia Atlantic coast. Bottom trawling and dragging, in addition to potentially altering the composition of the seabed and biological communities, can cause elevated suspended sediment levels, and scallop dragging can disturb the upper few centimetres of sediment and redistribute nutrients, organic carbon and contaminants if they are present (Mayer *et al.* 1991; Messieh *et al.* 1991).

Fishing is, however, the single most important source of persistent marine litter in offshore waters of the Scotian Shelf (Lucas 1992; Dufault and Whitehead 1994). On Sable Island, fragments of fishing nets, rollers and floats, as well as fish boxes, trap tags, salt bags and other miscellaneous items associated with the fishing industry account for 20% of all the litter observed. Reports from Canadian fisheries observers on foreign and domestic fishing vessels have shown routine ocean dumping of garbage on 73% of trips in the offshore (Lucas 1992).

Hydrocarbon Development

Hydrocarbon development on the Scotian Shelf is modest by world standards; between 1967 and 1988, 260 exploratory wells were drilled on the outer Banks and slopes of the Scotian Shelf, predominantly in the Sable Island area (Gordon 1988). The first commercial production began in 1993 at the Cohasset-Panuke site southwest of Sable Island, and production from the first phase of the Sable Offshore Energy Project began in 1999, consisting of three wells in the vicinity of Sable Island and a pipeline to shore. Further production and development activity in the area is ongoing (September 2001) and more is likely to occur.

Drilling and production activities for offshore hydrocarbon development can be a source of various chemicals in the marine environment, chiefly substances used in drilling (e.g. drilling muds and lubricants); and cuttings and water from undersea rock formations (produced water) which are released at the surface. Cuttings and produced water comprise the largest volume of

wastes discharged from typical exploratory drilling operations, while produced water accounts for the largest volume of waste released during hydrocarbon production phases (Table 1.11).

Table 1.11. Typical lifetime quantities of wastes discharged during offshore oil and gas exploration and production activities (from GESAMP 1993).

	Approximate Amounts (tonnes)
Exploration sites (ranges for a single well)	
Drilling mud - periodically	15 to 30
- bulk at end	150 to 400
Cuttings (dry mass)	200 to 1,000
Base oil on cuttings	30 to 120 [1]
Production site (multiple sites)	
Drilling mud	45,000 [2]
Cuttings	50,000 [2]
Production water	1,500 / day [3]

[1] Actual loss to environment may be higher (Chenard *et al.* 1989)
[2] Estimate based on 50 wells drilled from a single offshore production platform, drilled over 4 to 20 years (Neff *et al.* 1987)
[3] From a single platform (Menzie 1982)

Produced water is released by offshore operations, typically in larger quantities as the well ages. In addition to various salts and residual hydrocarbons, nutrients such as ammonia and silica, produced water may contain a variety of metals in higher concentrations than in seawater—barium, beryllium, cadmium, chromium, copper, iron, lead, nickel, silver and zinc—as well as radionuclides (^{226}Ra and ^{228}Ra) (Neff *et al.* 1987) (Table 1.12).

Constituent	Concentration (mg L^{-1})
Chloride	57,000.0
Sodium	32,500.0
Calcium Carbonate	8,300.0
Potassium	550.0
Magnesium	446.0
Strontium	223.0
Sulfate	137.0
Total Organic Carbon	119.0
Barium	65.0
Iron	53.0
Ammonia	36.1
Silica	28.0
Boron	6.9
Manganese	2.6
Other: pH	6.7
Turbidity	23.4 NTU
Total Suspended Solids	125.0 mg L^{-1}

Table 1.12. Constituents of produced water from the Cohasset/ Panuke production site southwest of Sable Island (from Muschenheim *et al.* 1995).

Drilling muds released into the marine environment may contain barium sulphate (barite—a weighting agent); iron and chromium (in mud additives); paraffin- or synthetic-based oil (a lubricant in oil-based muds used in many offshore wells on the Scotian Shelf); and may also include trace metals including arsenic, cadmium, copper, lead, mercury, nickel and zinc, although the metals found most frequently at concentrations above natural levels are barium, chromium, lead and zinc (Neff *et al.* 1987). Effects such as elevated metal concentrations or altered seabed from the presence of cuttings and associated materials on the Scotian Shelf have usually been localized within a few kilometres of drill sites (Yunker and Drinnan 1987; Carter *et al.* 1985). But some mud components have been found up to 14 km from an active Scotian Shelf platform (Muschenheim *et al.* 1995). In contrast, effects of produced water are generally not observed beyond a few hundred metres of an active platform.

Rig operations also produce associated releases including human domestic sewage and deck drainage (usually with some form of treatment), cooling waters from machinery, particulates and gases from flaring, accidental releases of contaminants (e.g. hydrocarbons) associated with routine operations, and chemicals such as metals which may enter seawater from rig structures.

1.5 OVERVIEW OF CONTAMINANTS—SUMMARY AND CONCLUSIONS

This chapter has given an overview of some of the general issues and approaches in assessing the marine environmental quality of the Scotian Shelf and adjacent waters based on contaminants. In many respects, the problems and issues, as well as the approaches for assessing them are similar to those found world wide.

We will see in more detail in the following chapters how the local patterns of human activity in the marine environment of both coastal and offshore areas of the Scotian Shelf and adjacent waters are reflected in levels of contaminants in the waters, sediments and biota observed there.

2. CONTAMINANTS IN OFFSHORE AREAS

2.1 INTRODUCTION

An assessment of the environmental distribution of contaminants on the offshore portions of the Scotian Shelf is limited in a number of ways. First, there have been few comprehensive studies of contaminants in the waters, sediments and biota of the Scotian Shelf. This situation reflects a lower level of concern here than for other, more-contaminated areas, based on limited studies which have suggested that the open ocean is relatively free of anthropogenic chemicals; but it also reflects research priorities (in which the pursuit of an understanding of the marine environment, resources, and contaminant behaviour has generally been given a higher priority than baseline and monitoring studies). The difficulty and expense of sampling the Scotian Shelf (an area bigger than the Province of Nova Scotia), has also been an important factor in limiting contaminant research here.

A second important factor limiting an assessment, has been that owing to changes with time in quality of information on contaminants and in our understanding of their behaviour, the period over which there is reliable data is relatively short. The scientific study of environmental contaminants is relatively young—in fact most of the methods and approaches to the study of contaminants in the marine environment have been developed in the past three decades. Many of the conclusions reached at the beginning of this period were thus often based on inadequate methods or understanding, while rapid changes in analytical methods and sampling procedures, have frequently cast into doubt, data collected in earlier times.

To take trace metals as an example, there have been no surveys of levels in sediments on the Scotian Shelf as a whole; while studies of concentrations in the water column have been limited to specific locations. Furthermore, results of key early studies may be inaccurate due to inadequacies of early sampling and analysis procedures. As another example, commercial catch of fish and samples of fish products have been variously examined for the presence of contaminants of concern to human health. Rarely have these studies been sufficiently detailed to describe patterns of geographic distribution of contaminants, patterns within a given species, or any measurements over periods longer than a few years. Because of the uncertainties associated with contaminant measurements, more weight should be placed on information produced from 1980 to the present, but early work has been included where available.

2.2 METALS

Metals are key components of the spectrum of natural chemicals in the ocean, and are also one of the main groups released by human activities. They are important because some are potentially toxic to biological organisms in certain circumstances. Metals, such as copper, zinc, and iron, are essential in low concentrations to normal functioning of biological organisms, but are harmful at high concentrations. Others, for example mercury, cadmium, and lead—do not serve a biological function and can be harmful even at low concentrations (Ray and Bewers 1984; Viarengo *et al.* 1988). Typically the harmful effects of metals stem from impairing enzyme function and ion exchange processes which, in extreme cases, can impact all physiological processes of an exposed organism.

The concentration of dissolved and suspended metals in seawater and sediments depends on many factors:

- specific chemistry of the metal;
- interactions with living and non-living material;
- water masses and mixing processes;
- locations and amounts of inputs; and
- exchange processes with sediments and atmosphere.

Only rarely have concentrations of any metal of concern on the Scotian Shelf exceeded 'safe' limits for the functioning of the marine ecosystem or for human consumption as regulated by law. One such example, the occurrence of levels of mercury above regulatory limits of 0.5 ppm in swordfish in the early 1970s forced a ban on sale of that species for human consumption (it was lifted in 1979) (Eaton *et al.* 1986). In that case, however, levels of mercury in swordfish were thought to be mostly of natural origin (Freeman *et al.* 1974).

2.2.1 Dissolved and Particulate Metals in Seawater

Metal concentrations in waters of the Scotian Shelf are low and have not been discernably impacted by anthropogenic contamination. Except for iron and manganese, trace metal concentrations are lower than in other coastal areas of the world (Yeats *et al.* 1978), and only for cadmium and possibly for zinc have human influences increased the amounts entering the Western North Atlantic and in particular the Scotian Shelf, although changes in concentration there have not been detected (Yeats and Bewers 1983; Ray and Bewers 1984). The present pattern of metal distribution and abundance thus reflects the natural metal regime.

Some metals, such as molybdenum, are largely chemically unreactive. Their concentrations can be predicted both vertically and horizontally knowing inputs to the ocean, and knowing the degree of dilution and mixing that takes place (Ray and Bewers 1984). Other metals, for example, zinc, nickel, copper, cadmium and aluminum, have an affinity for particles, are active in biological processes, and show distributions similar to those of nutrients (Stoffyn 1984). Iron and manganese, both found in relatively high concentrations in inshore waters on the Scotian Shelf, participate in both chemical and biological processes in the water column, while manganese is evidently also released into the water column as the result of chemical processes in offshore sediments (Yeats and Bewers 1985).

Horizontal Distribution

The main sources of metals—atmospheric input, human releases in coastal areas, river discharge and water masses impinging on the area—influence the local distribution of metals in surface waters over the Scotian Shelf. By far the largest sources are the waters exiting the Gulf of St. Lawrence and the Labrador Current. These two sources impinge on different areas of the Scotian Shelf, the Gulf of St. Lawrence outflow forming the Scotian Current in the mid-region and the Labrador Current contributes at the shelf edge. Together, these flows comprise about 70% of the freshwater inflow for the east coast of North America, and a substantial part of the input of

anthropogenic and naturally occurring metals (Yeats 1993). Mixing of these flows with other water masses found on the shelf, forms the Scotian Shelf surface water mass and strongly influences the pattern of metal concentrations.

In general, metal concentrations in surface waters (the upper 50 m of the water column) decrease east-to-west and north-to-south over the Scotian Shelf, as the Gulf of St. Lawrence and Labrador Current are diluted through mixing with other water masses. The distribution of dissolved copper, which is elevated in the Gulf outflow (dissolved manganese is also elevated), illustrate this pattern (Figure 2.1). Vanadium, which is present in higher concentrations in oceanic waters, shows a reverse pattern (Yeats 1992), depending on season and degree of biological productivity. Areas having elevated primary productivity are likely to have lower metal concentrations in surface waters. For example, Bewers *et al.* (1976) showed that the surface Slope Water that lies off the shelf edge (Figure 2.2) has lower concentrations of most metals than shelf waters or the water mass immediately below it (Figure 2.3), presumably because a greater quantity of metals are incorporated in the biomass associated with the greater level of biological production which occurs there.

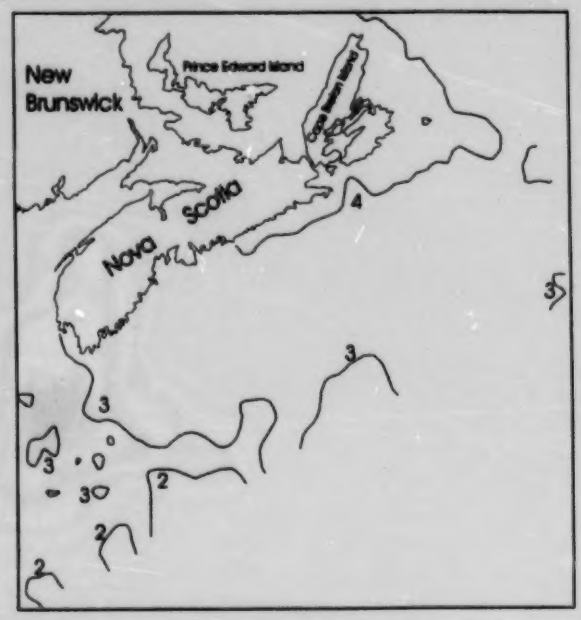


Figure 2.1. Horizontal distribution of dissolved copper (nanomoles per Litre) in surface waters of the Scotian Shelf (Dr. P. Yeats, DFO, Personal Communication, 2001).

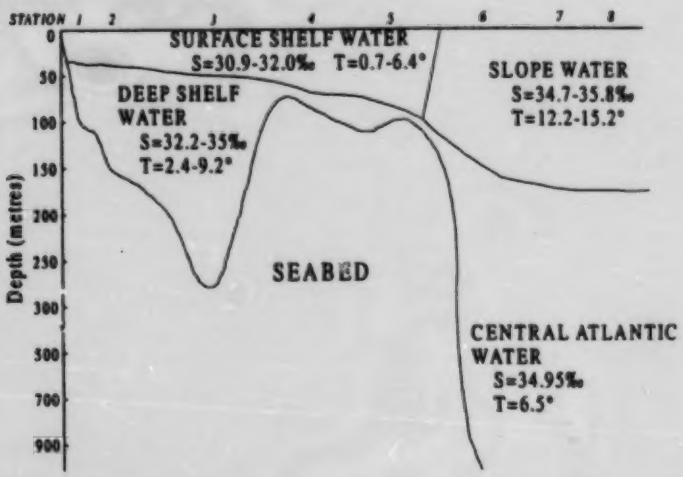


Figure 2.2. Major water masses on the Scotian Shelf, looking East through a cross-section of the Central Shelf (from Bewers *et al.* 1976).

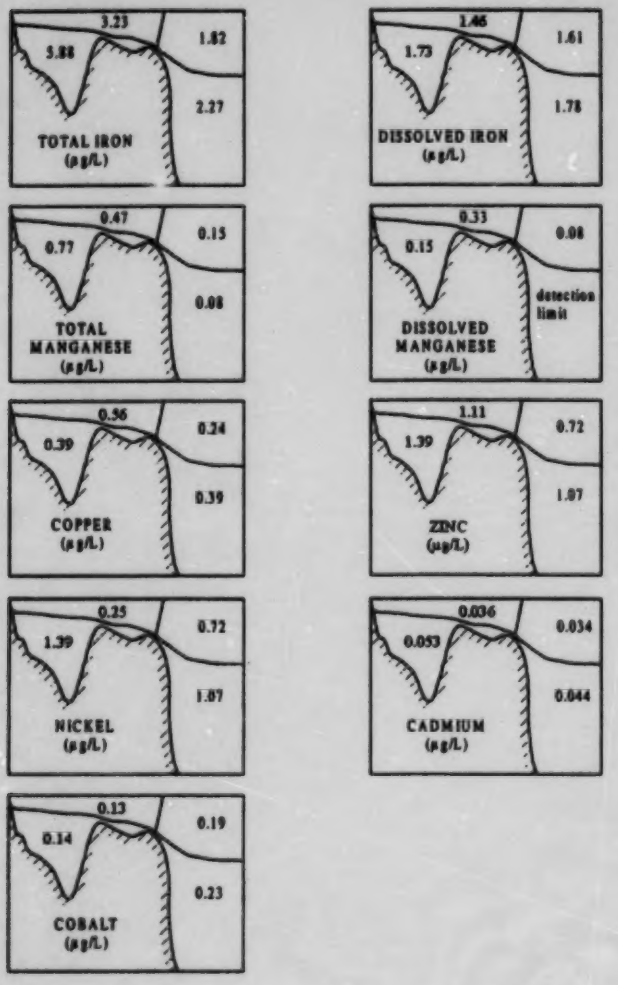
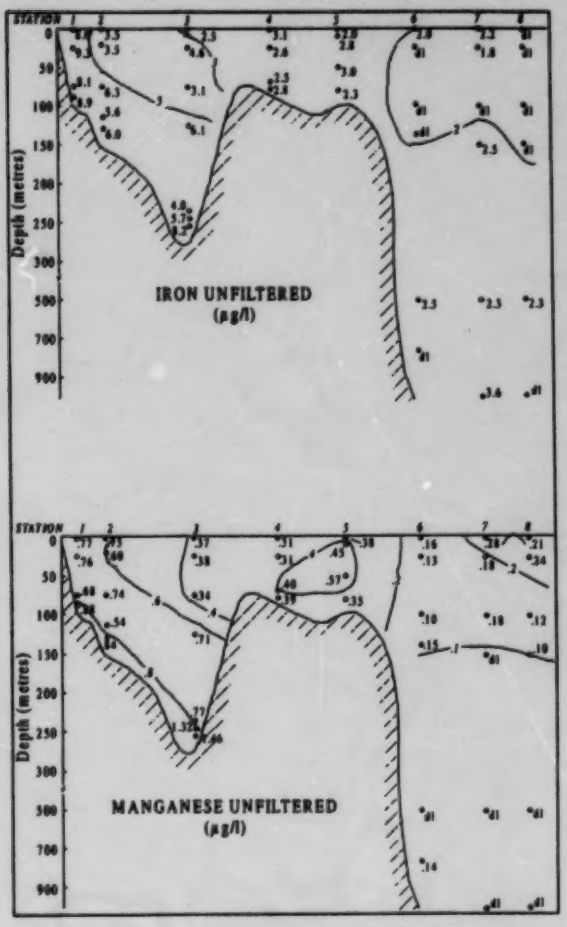


Figure 2.3. Concentration of metals in major water masses on the Scotian Shelf (from Bewers *et al.* 1976). Watermasses are shown in Figure 2.2.

Concentrations of most metals in coastal areas are slightly elevated over offshore levels because the influence of river input and releases from sediments are concentrated in those areas. With the exception of iron and manganese, metal inputs from rivers and anthropogenic sources have a relatively minor effect on concentrations observed on the Shelf (Bewers *et al.* 1976). Concentrations of metals (dissolved and particulate) even in the highly industrialized harbours are only slightly elevated over oceanic averages (Dalziel *et al.* 1991; Yeats, DFO, personal communication). Levels of other metals in nearshore waters are comparable to those of the Central Atlantic Water mass (the water mass beyond the shelf edge at depths >200 m and representing open ocean values) (Bewers *et al.* (1976) (a precise comparison cannot be made because analysis techniques and sampling methods have improved significantly since early studies).

Vertical Distribution

Patterns of vertical distribution of metals have been demonstrated by Bewers *et al.* (1976) who sampled vertical profiles from the surface to bottom on a transect across the Scotian Shelf (Figure 2.3), and Stoffyn (1984), who sampled the Slope Water to demonstrate patterns of metal distribution attributable to biological processes. Metals including zinc, nickel, copper, cadmium and aluminum have low levels in the upper 30 metres of the water column because they are incorporated into surface phytoplankton. Higher concentrations occur at 30 to 100 m depth (a pattern similar to that of the nutrients silicate, phosphate and nitrate) where the substances are released from decomposing phytoplankton and other organic matter (Stoffyn 1984; Ray and Bewers 1984). The increase occurs, however, at shallower depths than nutrients, suggesting release earlier in the decomposition process (Stoffyn 1984).



Iron in seawater precipitates onto particles or forms colloids which gradually settle to the seabed (Bewers *et al.* 1976), while its distribution may show depletion in surface waters through involvement with plant biomass and production (Stoffyn 1984). Manganese, while showing involvement in biological cycles in surface waters, has a unique distribution. Releases of dissolved manganese from sediments in basins on the Scotian Shelf, form particles in suspension through a process of chemical precipitation, so that bottom waters have levels of particulate manganese which are elevated over shallower waters (Bewers *et al.* 1976; Yeats, DFO personal communication) (Figure 2.4).

Figure 2.4. Distribution of total iron and manganese across the Scotian Shelf (from Bewers *et al.* 1976).

2.2.2 Metals in Sediments

Metals released into the ocean from natural sources and from discharges from human activities, attach to suspended particles, and are deposited on the seabed as the particles settle. In inshore areas, the resulting concentrations of metals in the sediments of bays, estuaries and harbours reach levels significantly greater than those in offshore sediments. Little information is available on concentrations of metals in offshore sediments on the Scotian Shelf, however, and no systematic studies have been undertaken, but concentrations in offshore sediments are likely to be low. Ranges of metals found in various studies are presented in Table 2.1 and in general demonstrate concentrations below those found in coastal sediments.

Metal	Concentration (µg/g dry weight)	Location
Barium	57 - 211	Sable Island Bank
Cadmium	0.01 - 0.10	Sable Island Bank, Scotian Shelf and Slope
Chromium	1.7 - 32.9	Sable Island Bank
Copper	0.39 - 10	Sable Island Bank, Scotian Shelf and Slope
Manganese	560	Emerald Basin
Lead	1.5 - 15.2	Sable Island Bank, Scotian Shelf and Slope
Mercury	0.01 - 0.14	Sable Island Bank, Scotian Gulf and Slope
Zinc	1.4 - 41	Sable Island Bank, Scotian Gulf and Slope
Sources: Hawkins from Mobil (1983); Carter *et al.* (1985); Bewers *et al.* (1976)		

Table 2.1. Concentrations of trace metals in uncontaminated surface sediments on the Scotian Shelf.

Elevated metal concentrations can occur in the vicinity of oil exploration and production facilities, typically in the phases involving drilling. Water-based drilling muds (used in the industry to stabilize the borehole, transport cuttings to the surface, lubricate the bit and provide pressure control), may have emulsifier chemicals that contain heavy metals, typically chromium and iron. Owing to high dispersion of the oceanographic regime near Sable Island, one drill site showed a relatively low accumulation of barium, copper and mercury within 0.5 km of the well site immediately after drilling ceased. Although accumulations of barium and copper were 2-3 times the pre-drilling levels, while mercury reached approximately 20 times the pre-drilling level, metal levels were low compared with nearshore sediments (Carter *et al.* 1985). There have been, however, no long-term studies of contamination in the area arising from exploratory drilling. These inputs decline after the drilling phase, and have not been detected at elevated levels following drilling in the area (Carter *et al.* 1985) (Table 2.2).

Table 2.2. Concentrations of trace metals in sandy surface sediments in the vicinity of Sable Island (from Carter *et al.* 1985).

Metal	Concentration (µg/g dry weight)	
	Pre-drilling Control [1]	Control Site [2]
Barium	56.6 - 211.3	147.0
Chromium	1.7 - 32.9	12.2
Zinc	1.4 - 14.6	6.0
Lead	1.5 - 6.5	8.9
Copper	0.39 - 1.54	1.79
Mercury	0.01 - 0.14	0.01
Cadmium	0.03 - 0.10	0.05
[1] 4-9 km northwest of Sable Island. 38-55 m. [2] 55 km northwest of Sable Island. 44 m.		

2.2.3 Metals in Biota

No recent assessments of metal concentrations in biota on the Scotian Shelf have been made though measurements of key contaminants have been made by Fisheries and Oceans Canada (but not published) (and now the Canadian Food Inspection Agency) to determine acceptability of commercial catch for human consumption (for a selection of regulatory levels, see Table 1.2). In the early 1970s, concentrations of total mercury in a range of Scotian Shelf fish were generally low (Freeman *et al.* 1974). The exceptions were large fish having long life spans such as swordfish, tuna, sharks, dogfish, large halibut and larger offshore lobsters (Zitko 1981). Total mercury contents in swordfish from the North Atlantic above 1 µg/g

led to a ban on consumption of swordfish, but the mercury was likely of natural origin (Freeman *et al.* 1974). The methylmercury concentrations for a range of species for the Scotian Shelf were generally comparable to those in other uncontaminated marine areas (Zitko *et al.* 1971) (Table 2.3).

	Concentration in Muscle	
	Methylmercury (µg/g)[1] (wet weight)	Total Mercury (µg/g)[2] (wet weight)
Atlantic salmon (*Salmo salar*)	–	0.07 - 0.14
Atlantic herring (*Clupea harengus harengus*)	0.12	0.06 - 0.12
Atlantic halibut (*Hippoglossus hippoglossus*)	0.03	0.16 - 0.26
Silver hake (*Merluccius bilinearis*)	0.03 - 0.05	0.04 - 0.09
Red hake (*Urophycis chuss*)	0.03	0.06 - 0.19
Haddock (*Melanogrammus aeglefinus*)	0.04	0.06 - 0.19
Cusk (*Brosme brosme*)	–	0.09 - 0.15
Polluck (*Pollachius virens*)	0.04	0.05 - 0.13
Wolffish (*Anarhichas lupus*)	0.09	0.09 - 0.31
Lumpfish (*Cyclopterus lumpus*)	trace	0.04 - 0.10
Menhaden (*Brevoortia tyrannus*)	–	0.07 - 0.11
Squid (*Loligo forbesi*)	–	0.06 - 0.11
Rock crab (*Cancer irroratus*)	–	0.08 - 0.16
Redfish (*Sebastes marinus*)	–	0.11 - 0.16
Atlantic cod (*Gadus morhua*)	0.03	0.10 - 0.34
Gaspereau (*Alosa pseudoharengus*)	0.05	0.05 - 0.29
American plaice (*Hippoglossoides platessoides*)	0.07	0.12 - 0.15
Winter flounder (*Pseudopleuronectes americanus*)	–	0.11 - 0.20
Shad (*Alosa sapidissima*)	–	0.07 - 0.11
Sea Raven (*Hemitripterus americanus*)	0.03 - 0.05	0.15 - 0.45
Thorny skate (*Raja radiata*)	0.04 - 0.24	0.12 - 0.41
Red crabs (*Geryon quinquedens*)	–	0.21 - 0.59
American lobster (*Homarus americanus*)	–	0.15 - 1.53

[1] Zitko *et al.* 1971
[2] Freeman *et al.* 1974

Table 2.3. Concentration of methylmercury and total mercury in fish and shellfish tissue, Scotian Shelf and Nova Scotia coastal areas.

Cadmium concentrations in fish and fish products have also been a concern, although concentrations have been suggested to be of natural origin. In fish and shellfish from offshore areas, cadmium concentrations were found to be at acceptable levels (Tables 2.4 and 2.5), but sea scallops (*Placopecten magellanicus*) on some Scotian Shelf Banks (e.g. Browns) have higher concentrations than in some contaminated coastal areas (Uthe and Chou 1987). Body burden of cadmium among several metals in sea scallops was higher on Georges than on Browns Bank (Ray *et al.* 1984) (Figure 2.5, Table 2.6).

Table 2.4. Concentration of cadmium in tissues of sea scallop (*Placopecten magellanicus*) from areas of Eastern Canada (from Uthe and Chou 1987).

Reference	*Concentration (µg/g wet weight)*		
Location	Adductor Muscle	Digestive Gland	Soft Tissue Residue
Bay of Chaleur Petit Rocher	0.348	78.38	1.51
Belledune Harbour	0.257	61.15	–
Browns Bank	0.338	291.3	–
Passamaquoddy Bay	0.121	69.41	–
Georges Bank	0.121	98.25	1.08

Table 2.5. Cadmium levels (µg/g wet weight) in shellfish from commercial catch including the Scotian Shelf (from Uthe *et al.* 1979).

Species/tissue	*Cadmium (µg/g wet weight)*
Blue Mussel / shucked	0.08 - 2.0
Lobster / digestive gland	2.8 - 68
Lobster / white meat	0.03 - 0.58
Scallop / adductor muscle	0.06 - 0.39
Rock Crab / digestive gland	0.54 - 20.58
Rock Crab / white meat	0.06 - 0.16
Oyster / shucked	0.11 - 1.14

Figure 2.5. Relationships of total body load of Cu, Zn, Cd and Pb in scallops to shell height, Georges Bank (n=16) and Browns Bank (n=12) (from Ray *et al.* 1984).

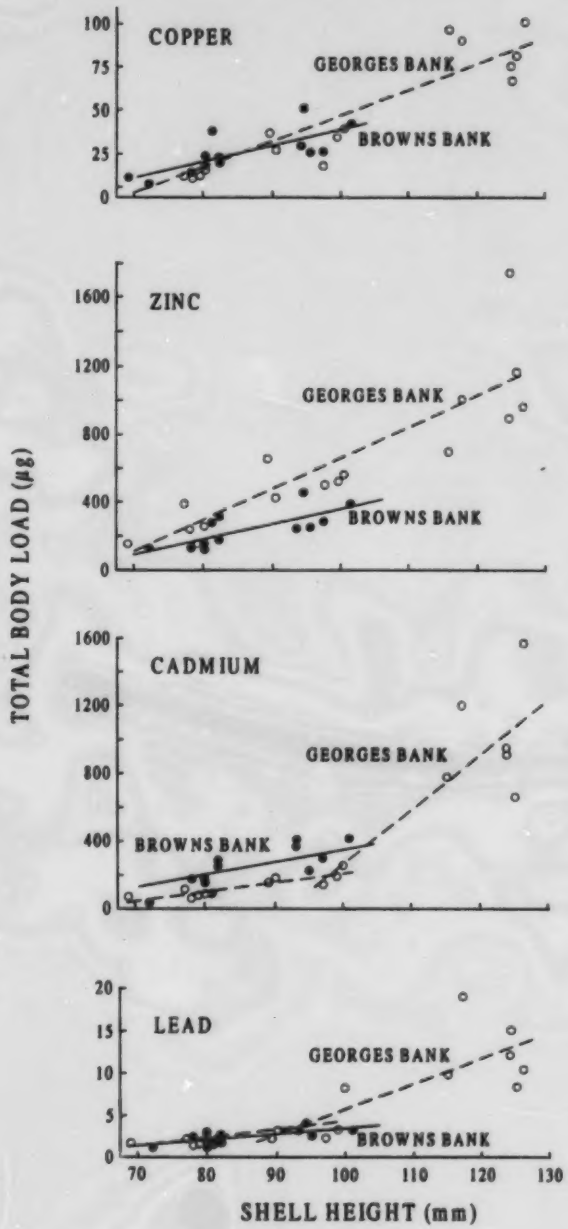


Table 2.6. Concentrations of copper, lead and zinc in sea scallop (*Placopecten magellanicus*) tissue from Eastern Canadian marine areas (from Ray *et al.* 1984).

	Concentration (µg/g wet weight)					
Area	Copper		Lead		Zinc	
	Muscle	Viscera	Muscle	Viscera	Muscle	Viscera
Bay of Fundy	–	11	0.2	2.4	70	88
Browns Bank (Scotian Shelf)	–	63	0.6	3.4	112	191
Georges Bank	–	12	0.6	0.96	65	101

Arsenic occurs naturally in the environment, is a component of pest control products and wood treatments and is a residue from gold mining which has taken place widely on watersheds discharging on the Atlantic coast of Nova Scotia. Elevated concentrations have been observed in lobster and sediments from coastal areas of Nova Scotia (Freeman and Uthe 1984; Loring *et al.* 1996). Levels in fish from the catch on the Scotian Shelf have occasionally exceeded 100 µg/g wet weight but were generally lower (Uthe *et al.* 1979) and not likely to be harmful to humans (Table 2.7). Generally the organic (less toxic) form of arsenic predominates (Uthe *et al.* 1979).

Table 2.7. Concentration of arsenic in commercial catch including the Scotian Shelf (µg As/g wet weight) (from Uthe *et al.* 1979).

Species tissue	Total arsenic	Inorganic arsenic
Clams shucked	1.8	0.5
Shrimp / tail muscle	3.9	0.5
Haddock / muscle	10.0	0.5
Crab / white meat	3.7	0.5
Mackerel / muscle	1.5	0.5
Herring / muscle	1.4	0.5
Lobster / tail muscle	40.5	0.5
Lobster / digestive gland	22.5	0.9

Lead occurs in fish tissue in Eastern Canada at low levels (generally less than 0.5 µg/g wet weight), both in an organic (tetraethyl lead) as well as an inorganic form. Tetraethyl lead (a gasoline additive released through widespread use of this product before lead levels in gasoline were regulated in the early 1980s) has been found to contribute 9 to 91% of the total lead in fishery products (Uthe *et al.* 1979) (Table 2.8).

Table 2.8. Tetraalkyl lead and lead concentrations in commercial catch including the Scotian Shelf (μg Pb/g wet weight) (from Uthe *et al.* 1979).

Species / tissue	R_4Pb	Pb total	Ratio (%)
Cod / liver	0.03 - 0.13	0.21 - 0.52	9 - 24
Mackerel / muscle	0.05	0.14	39
Lobster / digestive gland	0.13	0.20	80
Flounder / meal	4.8	5.3	91
Yellow perch / muscle (Lake Erie, Ontario)	0.01 - 0.22	0.07 - 0.48	13 - 77

Data on other metals in the marine fauna from Eastern Canada are limited (Zitko 1981). Carter *et al.* (1985) found chromium and zinc in the tissues of scallops around a drill site 5 km north of Sable Island.

2.3 SYNTHETIC ORGANIC CHEMICALS AND HYDROCARBONS

Chemical compounds having carbon in their molecular structure are known as organic chemicals. They can range from relatively simple compounds having a single carbon atom (methane) to complex structures having rings and chains and incorporating other elements substituting for carbon and hydrogen in places in the structure. Organic chemicals are generally only sparingly soluble in water, and have a high affinity for suspended particulate material. In biological organisms, they are more likely to be found in the fatty tissues (lipids); thus significant concentrations can occur in biota relative to other compartments of the environment. The majority of measurements of organic chemicals in the environment on the Scotian Shelf have been carried out in coastal areas (See Section 3, Contaminants in Coastal Areas).

In inshore and offshore areas of the Scotian Shelf, fish and fishery products as well as seals have been sampled periodically to measure levels of organic chemicals such as organochlorine pesticides (e.g. DDT, DDE) and PCBs. Here too, significant studies have been carried out on the distribution of hydrocarbons in water and sediments. There is, however, little other information specific to the Scotian Shelf on distribution, compartmentalization in the ecosystem, or fate and effects of organic chemicals.

2.3.1 Organochlorines and Other Synthetic Organic Chemicals

Organochlorine Compounds

The organochlorine group of chemicals includes many of the common pesticides, including DDT and its breakdown products DDE and DDD, as well as polychlorinated biphenyls (PCBs) (Table 2.9). Those commonly found in the marine environment include DDT and derivatives, cyclodiene, and HCH insecticides, industrial compounds such as PCBs, and hexachlorobenzene

(HCB) and pentachlorophenol, both of which are fungicides. Many other organochlorine compounds are used but have not yet been reported in the marine environment (Harding 1986).

Organochlorines, particularly DDT and its derivatives and PCBs, have been a concern principally because they tend to degrade only slowly and concentrate in animal tissues, leading to biomagnification. DDT and its derivatives were responsible for eggshell thinning that led to near extinction of peregrine falcons worldwide and fish-eating birds (double-crested cormorant and brown pelican) in North America in the 1950s and 1960s (Peakall 1993). Bans or restrictions on use of these substances in Canada and the United States in the early 1970s, have reduced inputs and are expected to result in reduced concentrations on the Scotian Shelf with time. There is little information, however, to allow trends in concentrations of organochlorines on the Scotian Shelf to be estimated.

Table 2.9. Organochlorine compounds detected in the marine environment (from Harding 1986).

p,p' - DDT	2,2-bis-(*p*-chlorophenyl)-1,1,1-trichloroethane
o,p' - DDT	2-(*o*-chlorophenyl)-2-(*p*-chlorophenyl)-1,1,1-trichloroethane
p,p' - DDE	2,2-bis-(p-chlorophenyl)-1,1-dichloroethylene
p,p' - DDD	2,2-bis-(p-chlorophenyl)-1,1-dichloroethane
Chlordane	Cis- and trans-isomers of 1,2,4,5,6,7,8,8-octachloro-3a,4,7,7a-tetrahydro-4,7-methanoindane
Dieldrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8a-octahydro-1,4-endo-exo-5,8-dimethanonaphthalene
Endrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo-endo-5,8-dimethanonaphthalene
Aldrin	1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-1,4-endo-exo-5,8-dimethanonaphthalene
Toxaphene	Chlorinated camphene (mixture, components resemble aldrin)
Heptachlor	1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene
Heptachlor epoxide	1,4,5,6,7,8,8-heptachloro-2,3-epoxy-2,3,3a,4,7,7a-hexahydro-4,7-methano indene
HCH	α-,β-,γ-,δ-isomers of 1,2,3,4,5,6-hexachlorocyclohexane
Lindane	γ-hexachlorocylohexane
PCBs	Isomers of polychlorinated biphenyls (mixture)

Water and Sediments—No measurements of concentrations of organochlorines in water and sediments are available for offshore areas of the Scotian Shelf, although some measurements have been made in coastal sediments (See Section 3).

Fish and Shellfish—Levels of important organochlorines have been determined in fish, shellfish and fishery products and in seals in a number of studies (Sims *et al.* 1975, 1977; Zitko 1971, 1978, 1980; ICES 1977a from Zitko 1981); Zitko *et al.* 1974; Addison and Brodie 1977;

Addison 1984; Addison *et al.* 1984; Addison and Stobo 1993). With the exception of the marine mammal studies noted above, most organochlorine measurements were carried out in the 1970s during the period of most concern about the effects of these contaminants. In general, 1970s' levels of organochlorine pesticides and PCBs in fish were low, except for bluefin tuna (Zitko 1980) (Table 2.10). DDT levels in bivalve molluscs from the Scotian Shelf were comparable to lower values from coastal US areas and below levels from other contaminated areas (Sims *et al.* 1977; Addison 1984). PCB concentrations in cod liver from Browns and La Have Banks and Sydney Bight in 1975 (ICES 1977a from Zitko 1981) were lower than in the adjacent Gulf of St. Lawrence but higher than generally-considered pristine Arctic areas. Measurements of DDT and PCBs made in the 1970s may be suspect due to methodology used at the time.

Table 2.10. Concentration of organochlorines in fish tissues from Nova Scotia banks.

Species or Type	Year	Area	Tissue	Tissue Concentration (µg/g wet weight)			
				Total DDT	DDE	PCB	HCB
Groundfish (cod, hake, plaice & ocean perch) [1]	1970	Nova Scotia Banks	Muscle		< 0.02	< 0.02	--
Pelagic (Atlantic herring) [1]	1971	Chedabucto Bay	Muscle	43	24	54	6
Atlantic Herring [2]	1972	Nova Scotia Commercial Catch	Muscle	20	11	64	--
Cod [3]	1971	Atlantic Coast	Liver	4 - 14	--	--	--
	1971	Sydney Bight	Muscle	3	0.01	--	--
Bivalves (clams, mussels, oysters, scallops) [4]	1971-72	Atlantic Coast	Edible parts	0.003 - 0.015	--	0.005 - 0.023	0.001 - 0.003
Crustaceans (lobster, queen crab, red crab, rock crab, shrimp) [4]	1971-72	Atlantic Coast	Edible parts	0.0003 - 0.061	--	0.024 - 0.098	ND - 0.001
Groundfish (catfish, cod, grey sole, haddock, halibut, plaice, pollock, redfish, yellowtail) [4]	1971-72	Atlantic Coast	Edible parts	0.004 - 0.24	--	0.01 - 0.27	0.001 - 0.003
Pelagic fish (alewives, capelin, dogfish, eels, herring, mackerel, salmon, sardines, smelt, striped bass, swordfish) [4]	1971-72	Atlantic Coast	Edible parts	0.021 -1.1	--	0.057 - 0.94	0.006 - 0.02
Bluefin tuna [4]	1971-72	Scotian Shelf	Edible parts	0.6 - 7.3	>1	0.6 - 9.7	0.002 - 0.005
Bluefin tuna [5]	1976-78	Scotian Shelf	Liver	2.0 - 10.6	2.4 - 6.2	4.6 - 25.1	0.004 - 0.044
Cod [6]	1975	Browns Bank	Liver	--	--	145	--
		LaHave Bank	Liver	--	--	205	--
		Northeast of Cape Breton Island	Liver	--	--	19	--
		Western Gulf of St. Lawrence (4T)	Liver	--	--	2.9 - 4.1	--
		Davis Strait and West of southern Greenland	Liver	--	--	0.43 - 0.45	--
Cod [7]		Inshore–Terence Bay	Liver	--	--	2.0 - 9.0	--

[1] Zitko (1971)
[2] Zitko *et al.* (1974)
[3] Sims *et al.* (1975)
[4] Sims *et al.* (1977)
[5] Zitko (1980)
[6] ICES (1977a) from Zitko (1981)
[7] Freeman *et al.* (1982)

The pesticide chlordane and nonachlors (chlordane contaminants) were detected at high concentrations (above levels of 0.1 µg/g in lipids considered unacceptable for human consumption, Health Canada, 1982) in livers from tuna captured off Nova Scotia and held in enclosures in St. Margaret's Bay in 1976-78 (Zitko 1980). These compounds have also been found at low levels in marine fish and shellfish from Eastern Canada (Zitko 1978).

Other organochlorine compounds have been detected in fish and shellfish species; tuna analyzed by Zitko (1980) had elevated liver concentrations of dieldrin, hexachlorobenzene, chlordane components (noted above), oxychlordane (a chlordane metabolite), toxaphene components, DDMU (a dechlorination product of the DDT breakdown product DDD), Mirex and octachlorostyrene (Zitko 1980). Zitko *et al.* (1974) also found hexachlorobenzene in Atlantic herring from the Scotian Shelf. In the early 1980s, toxaphene was found in the muscle of herring caught off Halifax (0.4 µg/g wet weight), but not in sea scallops from Georges Bank (Musial and Uthe 1983).

Marine Mammals—Grey seals (*Halichoerus grypus*) from Sable Island have been sampled periodically for organochlorine concentration, providing the only information on this group of contaminants in marine mammals from the inshore or offshore areas of the Scotian Shelf. Concentrations of DDT in grey seal blubber the mid-1970s were similar to those observed in the North Sea (the only area for which comparable data were available) while PCB concentrations were significantly lower (Addison 1984). Comparisons of organochlorine concentrations in blubber of female grey seals from Sable Island between the early to mid-1970s and 1982 showed a decline of about half in total DDT while PCB concentrations did not change (Figure 2.6, Table 2.11) (Addison *et al.* 1984). It is not known whether the levels are large enough to impact the biology of the species, but the decline is an indication of changing levels of these chemicals in the environment. The finding was the first clear indication that organisms in higher trophic levels on the Scotian Shelf had lower DDT levels as a result of the ban on DDT in Canada in 1969 and in 1972 in the US.

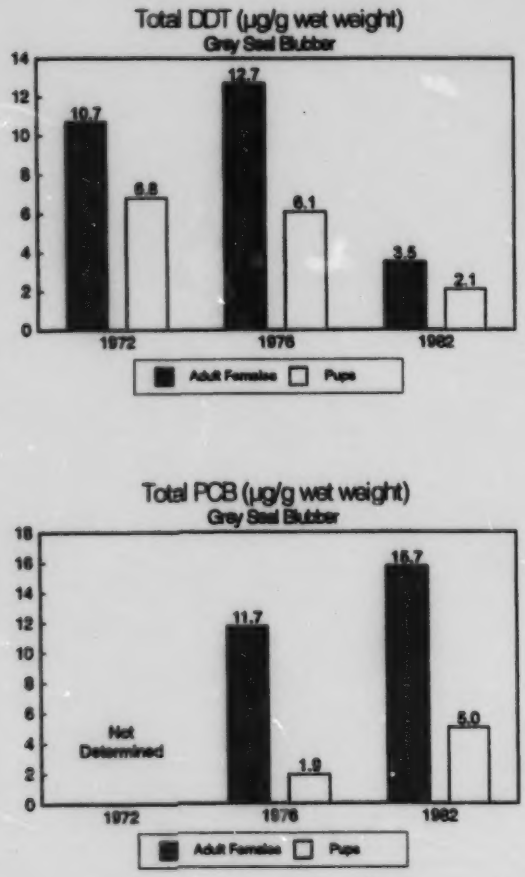


Figure 2.6. Changes in organochlorine concentrations (top) and PCB concentrations (bottom) in blubber of Grey seals (*Halichoerus grypus*) from Sable Island (from Addison *et al.* 1984).

	Concentration (µg/g wet weight) (means ± SD)		
	1974 (*n*=5)	1976 (*n*=6)	1982 (*n*=8)
MOTHERS			
p,p′-DDE	5.7 ± 2.0 [a]	7.5 ± 3.6 [a]	2.5 ± 0.8 [b]
p,p′-DDT	5.0 ± 3.0 [a]	5.3 ± 2.8 [a]	1.0 ± 0.2 [b]
ΣDDT	10.7 ± 4.9 [a]	12.7 ± 6.2 [a]	3.5 ± 1.0 [b]
p,p′-DDE as % ΣDDT	56.0 ± 10.3 [a]	59.7 ± 7.0 [a]	72.2 ± 2.6 [b]
PCB	ND [d]	11.7 ± 4.4 [a]	15.7 ± 5.8 [a]
age	ND	6.8 ± 1.2 [a]	14.5 ± 7.9 [c]
blubber thickness	3.7 ± 0.3 [a]	3.7 ± 1.1 [a]	4.8 ± 0.7 [b,c]
blubber lipid content	89.5 ± 3.1 [a]	82.3 ± 6.2 [c]	91.5 ± 3.0 [a]
PUPS			
p,p′-DDE	4.1 ± 1.6 [a]	3.8 ± 1.7 [a]	1.5 ± 0.6 [b]
p,p′-DDT	2.7 ± 1.0 [a]	2.3 ± 1.2 [a]	0.6 ± 0.2 [b]
ΣDDT	6.8 ± 2.6 [a]	6.1 ± 2.9 [a]	2.1 ± 0.8 [b]
p,p′-DDE as % ΣDDT	60.2 ± 1.6 [a]	63.0 ± 5.0 [a]	72.3 ± 2.1 [b]
PCB	ND	1.9 ± 0.7 [a]	5.0 ± 3.5 [c]
pup stage (range) (5)	I-III	II-IV	I-III
blubber lipid content	80.9 ± 8.2 [a]	83.2 ± 3.0 [a]	87.2 ± 12.3 [a]

[a] Data in the same row not significantly different by *t* test.
[b] Data in the same row differ significantly (P<0.01) by *t* test.
[c] Data in the same row differ significantly (P<0.05) by *t* test.
[d] ND, not determined.

Table 2.11 Comparison of organochlorine residue concentration (µg/g wet weight), age (years), blubber thickness (cm), and lipid content (% wet weight) in Sable Island Grey Seal (*Halichoerus grypus*) mother-pup pairs sampled in 1974, 1976 and 1982 (from Addison *et al* 1984).

The organochlorine compounds in grey seal pups sampled in 1988-91 included *p,p'*-DDE, *p,p'*-DDT, PCB, hexachlorobenzene (HCB), hexachlorocyclohexane and *trans*-nonachlor, similar to that in animals sampled in the 1974-82 period (Addison and Stobo 1993). Concentrations were similar to those from the earlier studies and in some cases were slightly lower for pups at a comparable stage of development (Addison and Stobo 1993). Typical levels in pup blubber are presented in Table 2.12 and Figure 2.7.

Table 2.12. Concentrations of organochlorine contaminants in blubber of grey seal (*Halichoerus grypus*) pups from Sable Island, 1974-76 and 1988-91 (from Addison and Brodie 1977 and Addison and Stobo 1993).

	Concentration (µg/g lipid)		
	1974 [1]	1976 [1]	1988-91 [2]
p,p′-DDT	1.7 - 4.2	1.7 - 5.4	0.24 - 0.61
p,p′-DDE	2.5 - 6.5	2.4 - 8.5	0.81 - 2.70
Total DDT	4.2 - 10.5	4.1 - 13.9	1.05 - 3.23
PCBs	–	1.4 - 3.2	1.59 - 4.90
HCB	–	–	0.010 - 0.139
α-HCH	–	–	0.053 - 0.164
Nonachlor	–	–	0.006 - 0.014

[1] Addison and Brodie (1977)
[2] Addison and Stobo (1993)

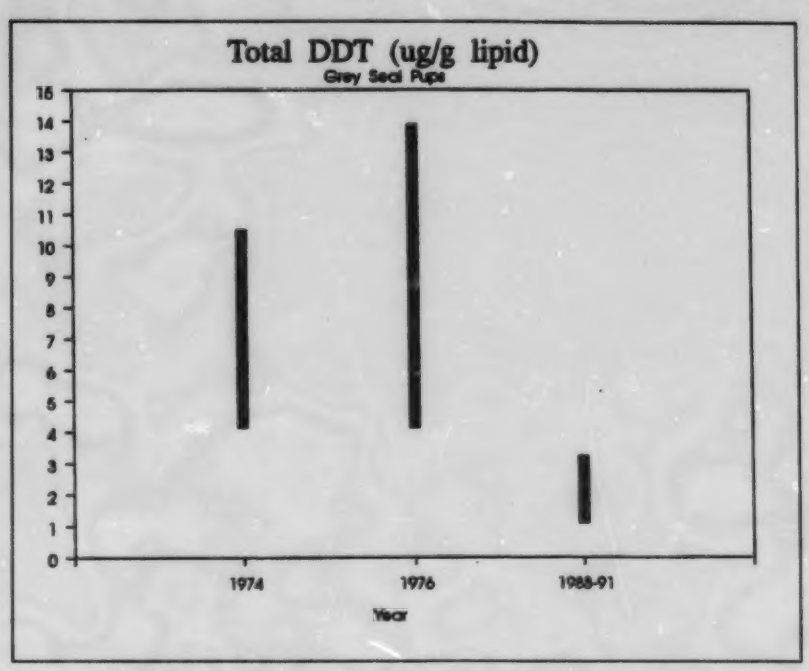


Figure 2.7. Changes in ranges of DDT concentration in blubber of Grey seal (*Halichoerus grypus*) pups from Sable Island, 1974-1991 (from Addison and Brodie 1977; Addison and Stobo 1993).

Other Organisms—Euphausiids on the Scotian Shelf in 1973-74 had concentrations of *p,p'*-DDT and *p,p'*-DDE similar to euphausiids in the St. Lawrence River estuary and the inner Gulf of St. Lawrence at the time, but mid-range with respect to levels of *p,p'*-DDT in ocean plankton (Harding 1986; Sameoto *et al.* 1975).

Other Synthetic Organic Chemicals

Tetraethyl lead, a synthetic gasoline additive, has been found in marine fish products from Nova Scotian waters (the location was not specified) (Uthe *et al.* 1979). Levels were below those which would cause human health concerns. The chemical di-n-hexyl phthalate (DHP), an unusual form of phthalic acid ester (a group of common plasticizer chemicals) was found in tissues of herring and mackerel in connection with studies of other chemicals in the Gulf of St. Lawrence (Musial *et al.* 1981). These species are both migratory and all or components of the populations may spend time on the Scotian Shelf for part of the year. The origin of the chemical is unknown since it is not found in industrial releases.

2.3.2 Hydrocarbons and PAHs

Hydrocarbons

Hydrocarbons, either released to the marine environment through spills of fuels or lubricants, blowouts or tanker accidents, or from natural sources, are an ubiquitous contaminant of the marine environment (Levy 1984; GESAMP 1993). The main anthropogenic source is marine

vessel traffic, while a small percentage comes from major hydrocarbon spills in tanker accidents (Levy 1971). Hydrocarbons are released naturally from seeps (the main natural source); while production by marine plants and zooplankton is a relatively minor contribution (Gordon *et al.* 1978; GESAMP 1993). Hydrocarbons can occur both in dissolved form and as particles ranging from microscopic to tar balls of various sizes, can exhibit complex chemical structures, and are found typically in mixtures having a complex suite of components.

Waters have been monitored periodically in evaluating the extent and significance of hydrocarbon contamination in offshore areas. Levels of hydrocarbons in water on the Scotian Shelf are low and variable, below those found in the northward flowing Gulf Stream that meets the Slope Water just beyond the shelf margin and lower than in the Sargasso Sea but slightly higher than in the adjacent Gulf of St. Lawrence (Levy 1984; 1988). Levy concluded that there appeared to be a downward trend throughout the 1970s in hydrocarbon concentrations in Scotian Shelf waters (Table 2.13).

Table 2.13. Hydrocarbon concentrations in surface waters on the Scotian Shelf.

Year	Area	Average Concentration (µg/L)	Range of Concentrations (µg/L)
1970 [1]	Inner Shelf		7 - 15
1970 [1]	Scotian Shelf		1.7 - 13.5
1973 [2]	Inner and Middle Shelf		1.4 - 11.9
1973 [3]	Scotian Shelf	2.4 - 7.3	
1974 [3]	Scotian Shelf	1.3 - 3.0	
1975 [3]	Scotian Shelf	0.35 - 0.45	
1975 [4]	Inner Shelf		0.2 - 2.0
1971-79 [3]	Cabot Strait	0.4 - 6.0	

[1] Levy (1971)
[2] Keizer and Gordon (1973)
[3] Levy (1984)
[4] Keizer *et al.* (1977)

Little information is available on the distribution and concentration of hydrocarbons in sediments on the Scotian Shelf; the few data indicate that sediments are relatively free of oil contamination. Concentrations of oil in sediments in the 1970s were low around Sable Island and on the middle shelf, and elevated levels were found only at two sites on the Inner Shelf approximately 30 and 60 km off Halifax Harbour (Keizer *et al.* 1978b). This study included abandoned well sites, and found no difference between concentrations in sediments there and at other sites. Although biologically-derived hydrocarbons were also found in sediments, the contribution of those arising from petroleum was greatest on the inner to middle shelf (Keizer *et al.* 1978b). Another study found low levels of hydrocarbons in sediments in areas where no drilling had occurred northeast and north of Sable Island (Yunker and Drinnan 1987).

PAHs

There is limited information on the concentration of PAHs in the offshore marine environment of the Scotian Shelf, although levels in biota and sediments have been measured in coastal areas in association with various pollution concerns (see Section 3). Elevated PAH concentrations found in some harbours are caused by extreme cases of contamination by residues from fossil fuel combustion (e.g. coke oven residues in the Sydney Harbour area), but in others by creosote from treated timbers used throughout the region in constructing wharves (Wells and Rolston 1991; Eaton and Zitko 1978) and formerly in lobster pounds (Uthe *et al.* 1984). As well as being byproducts of combustion and present in creosote, PAHs are in crude oil and processed

hydrocarbons such as diesel fuel and so can enter the marine environment when these substances are deposited there.

Natural environmental concentrations of PAHs on the Scotian Shelf have not been measured but are expected to be small. Seafood products, too, are unlikely to exceed recommended levels for safe human consumption. In Newfoundland and Labrador waters, Hellou *et al.* (1990) found generally low levels of PAHs in four species of seals and six whale species. Many of these species are known to move widely along the Eastern seaboard of North America and are expected to pass through Scotian Shelf waters.

2.4 CONTAMINANTS IN OFFSHORE AREAS—SUMMARY AND CONCLUSIONS

Despite many potential sources, offshore waters of the Scotian Shelf are largely uncontaminated with anthropogenic chemicals. This is in part because many of the contaminants (in particular metals and organic contaminants) have an affinity for particles and generally are deposited when the particles settle near the source of contamination—in standing water on land, and in estuaries, bays and inlets along the coast—and never reach far from shore. In estuaries, in particular, the chemical processes inherent in the mixing of fresh and salt water, enhance deposition.

Another factor is the generally low level of industrial activity in coastal areas of Nova Scotia and adjacent provinces and states, which limits the amounts of anthropogenic chemicals entering the marine system. Finally, and perhaps most important, the contaminant load reaching the Scotian Shelf is significantly diluted by the dominant influence of largely uncontaminated waters of the North Atlantic. The dilution of one type of contaminant—trace metals—is so great that concentrations observed on the Scotian Shelf are not measurably different from levels in the North Atlantic as a whole (Yeats and Bewers 1983); concentrations above offshore levels occur only within a few kilometres of shore (Bewers *et al.* 1976).

Nonetheless, anthropogenic chemicals at concentrations above background have been found on the Scotian Shelf. Hydrocarbons in water and organochlorine pesticides in biological organisms have been shown to occur at levels which are above those of the open ocean but are below those in other industrialized coastal waters (Levy 1984; Addison 1984).

This picture of contamination on the Scotian Shelf is, however, based on relatively few studies, sufficient in themselves to ensure that significant contamination by the wide range of possible chemicals was unlikely to occur, but only a few of which (such as the studies of hydrocarbons noted above) can claim to adequately sample and represent the area as a whole.

The level of knowledge and understanding of the contaminants of the Scotian Shelf is not unusual for continental shelves around the world. But it means that assessments of environmental quality in offshore areas must be viewed as provisional until further, more comprehensive studies, are carried out.

3. CONTAMINANTS IN COASTAL AREAS

3.1 OVERVIEW OF COASTAL ENVIRONMENTS

The indented Nova Scotia coastline forms a boundary between the offshore waters of the Scotian Shelf and the Nova Scotia landmass. Much of the coast is exposed to the open Atlantic Ocean, a fact, which coupled with its varying geological makeup, defines its local character, and sets it apart from the coastlines of the adjacent Gulf of St. Lawrence and Bay of Fundy. Exposed coastlines are typically rocky, wave-washed and coarse-grained. Back of the coast, in inlets, harbours and coves, and behind islands, the wave environment is less severe, and the sheltered conditions lead to deposition of fine sediments and reduced erosion. It is in these protected coastal areas, that most human settlement occurs, and where consequent effects (chiefly environmental contamination) are felt most significantly.

The coastline is also the site of entry to the ocean of Nova Scotia's rivers. Rising sea level has filled the valleys of many of the rivers which formerly drained out across the Scotian Shelf—these 'drowned' river valleys form many of the modern-day inlets (e.g. Shelburne Harbour, LaHave River estuary, Sydney Harbour). The estuarine conditions at their heads frequently result in intense physical/chemical activity that influences the availability and transformation of contaminants, often leading to enhanced contamination in areas where there are significant natural and anthropogenic contaminant sources.

Shallow depths along the coast from low tide level roughly to a depth of 30 metres—the approximate depth limit of the seaweeds— permit light to penetrate to the bottom, providing energy, throughout the water column, which fuels abundant biological life. In shallow waters too, estuaries are a distinctive feature which provide nutrients, and organic matter, to enhance biological productivity compared with other waters of the Scotian Shelf.

Taken together, the coastal areas of Nova Scotia form a complex and important system, and one that is closely linked to the dynamics of contaminants on the Scotian Shelf.

3.1.1 Character of the Coastline

The Atlantic coast of Nova Scotia is long—approximately 4,990 kilometres from the northern tip of Cape Breton Island to Briar Island (Owens and Bowen 1977)—and highly indented, carved out of mainly resistant metamorphic and igneous rocks, but also from softer sedimentary deposits such as the shales which occur in coastal areas in the coal-bearing Sydney Basin in northeastern Cape Breton Island (Figures 3.1 & 3.2, Table 3.1). In most areas, erosion by glaciers and subsequent drowning by a rising sea level have created an irregular coastline with numerous local embayments, islands and passages. Glacial till deposits, in particular drumlins, in some areas are responsible for coastal islands and frequently are the source of fine sediments which lead to the formation of beach and subtidal deposits. Coastal features caused by sediment transport and deposition—barrier beaches, lagoons, and extensive salt marshes behind them—are important features of most areas (Taylor *et al.* 1985; Owens 1977).

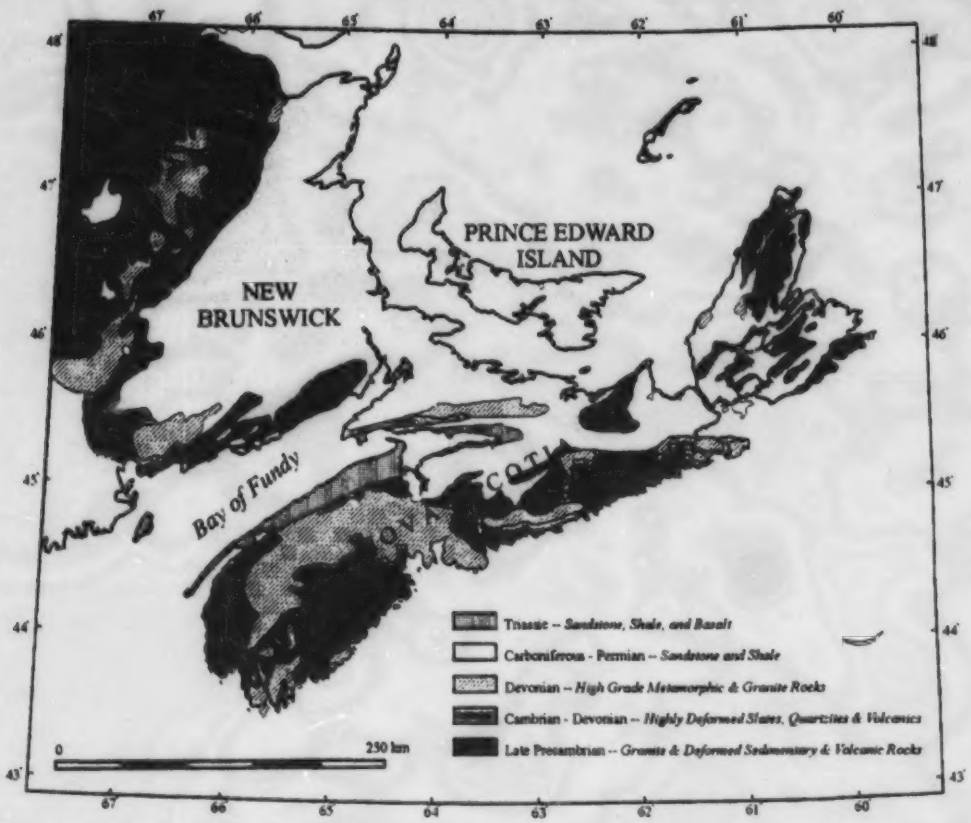

PRINCE EDWARD ISLAND
NEW BRUNSWICK
Bay of Fundy
Triassic -- Sandstone, Shale, and Basalt
Carboniferous - Permian -- Sandstone and Shale
Devonian -- High Grade Metamorphic & Granite Rocks
Cambrian - Devonian -- Highly Deformed Slates, Quartzites & Volcanics
Late Precambrian -- Granite & Deformed Sedimentary & Volcanic Rocks
0
250 km

Figure 3.1. Geology of the Maritime Provinces. From Owens and Bowen (1977).

Figure 3.2. Coastal regions of the Scotian Shelf, described in Table 3.1. From Owens and Bowen (1977).

Table 3.1. Characteristics of coastal environments of Atlantic Nova Scotia (from Owens and Bowen 1977). Locations are indicated on Figure 3.2.

Area	Geological Character	Relief	Beach Character	Fetch and Wave Exposure	Mean Tidal Range	Sediment Availability
1. Northeastern Cape Breton Island	Resistant metamorphic and igneous rocks; thin till cover.	Upland cliffed coast (5-100 m).	Absent or narrow; coarse sediments.	Exposed open ocean coast; ice-free 8-9 months.	1 m	Very scarce.
2. Eastern Cape Breton Island	Carboniferous sandstone or shale; thin till cover.	Rocky cliffs (5-20 m).	Occasional spits and barrier beaches. *	Exposed. Ice-free 8-9 months.	1 m	Scarce.
3. Southeastern Cape Breton Island	Carboniferous sedimentary and metamorphosed sedimentary rocks; thick till and drumlins.	Low rock and till cliffs (10-20 m)	Barrier beaches.	Exposed open ocean coast. Ice in sheltered areas up to 3 months.	1 m	Scarce but locally abundant.
4. Northern Chedabucto Bay	Carboniferous sedimentary rocks, some resistant volcanics, abundant till.	Low rock and till cliffs up to 20 m.	Spits and barrier beaches; coarse sediments.	Exposed in northeast, elsewhere sheltered. Ice-free 8-9 months.	1.5 m	Abundant.
5. Southern Chedabucto Bay	Resistant metamorphosed sedimentary and igneous rocks; fault-line coast; very thin till.	Rocky cliffs (3-10 m)	Absent or narrow; coarse sediments.	Sheltered. Ice-free 8-9 months.	1.5 m	Very scarce.
6. Eastern Shore	Resistant metmorphosed sedimentary and granitic rocks; tills of variable thickness and drumlins.	Indented low rocky coast; some eroded drumlins (30 m).	Absent or barrier/pocket beaches. Coarse sediments.	Exposed open ocean coast, sheltered embayments. Ice in sheltered areas 2-3 months.	1-2 m	Very scarce.

* Beaches forming across an inlet or channel mouth.

3.1.2 Physical Oceanography

The waters along the coast of Nova Scotia are dominated by small tides and a severe wave environment. Tides generally range from 0.9 m at Sydney to 3.7 m at Yarmouth but are usually less than 2 m along the Atlantic coast (Table 3.2). Winds which influence the wave climate are mainly offshore and out of the southwest. Waves which most strongly impact inshore environments arise from the passage of storms, and effects are most severe in winter, when waves of 4 metres or more are common. Shore ice forms in sheltered bays and persists for up to 4 months, but exposed coasts remain ice-free (Owens 1977).

Table 3.2. Tidal ranges for locations along Atlantic Coast of Nova Scotia (from Owens and Bowen 1977).

Location	TIDAL RANGE (metres)	
	Mean	Large
Ingonish Ferry	0.9	1.4
North Sydney	0.9	1.4
Louisburg	1.2	1.7
Guysborough	1.4	2.0
Halifax	1.4	2.1
Yarmouth	3.7	5.1

Waters in inshore areas are also influenced by freshwater inflow from rivers, streams, and groundwater seepage. Several of Nova Scotia's largest rivers—the Mersey, St. Mary's, Tusket, Medway and LaHave—discharge on the Atlantic coast, collectively leading to reductions in salinity of a few parts per thousand. The influence of freshwater, however, is small, owing to the fact that Nova Scotia rivers flowing into the Atlantic are small by world standards. Estuaries in these rivers, although minor, too, by world standards, can enhance biological productivity; while physical/chemical interactions of fresh and seawater lead to flocculation of suspended particulate matter and enhanced deposition of sediments and contaminants in some areas.

3.1.3 Plant Communities and Biological Productivity

The waters along the Nova Scotia coast are the most productive of the Scotian Shelf. Plant communities, the primary producers of the sea, including seaweeds on rocky bottom in intertidal and subtidal beds; eelgrass beds and saltmarshes in the fine sediments of sheltered coastal inlets; and microscopic algae (phytoplankton) in the water column, support an ecosystem ranging from bacteria and protozoa to zooplankton and benthic animals, and ultimately to fish and higher organisms such as marine mammals and seabirds.

The rocky coastline of the Nova Scotia Atlantic coast provides the essential solid substrate for the attachment of seaweeds, whose distribution, abundance, and associated organisms, closely parallel that of rocky bottom (Moore *et al.* 1986; Moore and Miller 1983). Although microscopic algae (phytoplankton) are important as food producers here, seaweeds provide the bulk of primary production in most areas (Mann 1972) while coastal flowering plants (eelgrass found subtidally and cord grass in salt marshes) make important contributions in areas where they are abundant. Animals feed on plants either by directly grazing on them (as in the case of sea urchins grazing on kelp), by filtering them from the water (e.g. mussels feeding on phytoplankton), or by feeding on detritus and attached microbial populations generated as seaweeds fragment or break off, and as phytoplankton decompose. Some of the detritus leaves coastal areas to deposit offshore while a proportion stays in coastal waters, eventually depositing in nearshore sediments. Seaweeds and phytoplankton also may shed polysaccharides (compounds consisting of long chains of sugars) and other organic compounds in dissolved and colloidal (long organic molecules) form, which become a food source for bacteria and some other organisms.

Shallow depositional environments (typically inlets and protected shores of bays) in coastal areas have subtidal beds of eelgrass (*Zostera marina*). Eelgrass beds, such as those occurring in Chezzetcook and Petpeswick Inlets, and in the Port Mouton to Port l'Hebert area, support a diverse animal community including overwintering waterfowl such as Canada geese and provide nursery areas and adult habitat for many fish species. The die-off and fragmentation of eelgrass by storms is an important source of detritus entering coastal ecosystems.

Sheltered environments often support salt marshes of cord grass (*Spartina* spp) and other characteristic species which extend from the subtidal to above the highest tides. Marshes exert a significant influence on coastal sedimentary conditions by promoting sediment deposition, creating organic enrichment of sediments, limiting circulation and flushing, aerating sediments, and serving as a source of particulate organic matter for coastal detrital food chains. Important saltmarshes on the Atlantic Coast of Nova Scotia occur at Chezzetcook and Lawrencetown on

Nova Scotia's Eastern Shore, at Tor Bay in Guysborough County, and commonly in coastal areas of southwest Nova Scotia.

The water column in coastal areas supports levels of production of phytoplankton which are greater than can be found in offshore areas of the Scotian Shelf, although seasonal patterns of growth and production mirror the general pattern for offshore areas. The spring bloom takes place in response to thermal stratification (warming and layer formation in the upper water column), and utilizes nutrients renewed in the water column over the winter. The phytoplankton populations, consisting chiefly of diatoms, decline in abundance as the nutrients are used up, and phytoplankton populations decline to a low level for the summer. In fall, mixing by winds brings nutrients to the surface and once again allows the secondary bloom to proceed (Platt *et al.* 1972). The influence of estuaries and nutrients brought by rivers, as well as regeneration from the seabed and upwelling processes also enhance local productivity. In some coastal areas, nutrients arising from inputs of untreated sewage discharges may raise nutrient levels and also primary productivity (e.g. Halifax Inlet, Petrie and Yeats, 1990).

Biological productivity in coastal areas supports abundant animal life, including many of Nova Scotia's commercial fisheries. Lobster, herring and mackerel occur commonly in inshore bays and inlets and shallow coastal areas, fished principally within a few kilometres of the coast, while many coastal areas support the growth of commercially important algae such as rockweed (*Ascophyllum nodosum*). Commercial species, however, form only a small part of the diverse assemblage of fish and other animal species which make up the coastal ecosystem (Table 3.3). The many undeveloped coastal inlets which offer clean water and adequate water exchange, make them ideal sites for the sea-farming of mussels, sea scallop, and salmon and trout—industries which are developing rapidly along the Nova Scotia coast.

Table 3.3. Typical biological communities from Nova Scotia inshore coastal waters.

PHYTOPLANKTON	ZOOPLANKTON	ZOOBENTHOS		MACROALGAE, FLOWERING PLANTS & BENTHIC MICROALGAE
HALIFAX HARBOUR	INSHORE	ROCKY INTERTIDAL	INTERTIDAL SAND/MUD	ROCKY INTERTIDAL
Chaetoceros sp	*Aglantha digitale*	*Balanus crenatus,*	*Chiridotea tuftsi*	*Ascophyllum nodosum*
Coscinosira sp	Brachyuran larvae [1]	*B. improvisus*	*Corophium* sp	*Callothrix* sp
Fragillaria crotonensis	*Calanus hyperboreus*	*Corophium* spp	*Littorina* spp	*Fucus* spp
Nitzschia delicatissima	*Calanus glacialis*	*Gammarellus* sp.	*Orchestia* sp	*Pennate diatoms*
Skeletonema costatum	*Limacina* sp	*Gammarus* spp.		*Rivularia* sp
Thalassiosira decipiens	*Metridia longa*	*Idotea* spp	SUBTIDAL SAND/MUD	
T. nordenskioldi	*Parathemisto gaudichaudi*	*Jaera marina*		SUBTIDAL ROCK & GRAVEL
Thalassiothrix nitzschioides	*Pseudocalanus minutus*	*Littorina* spp	Molluscs	
	Sagitta elegans	*Mytilus edulis, M. trossulus*	*Arctica islandica*	*Agarum cribrosum*
SAMBRO & MAHONE BAY	*Temora longicornis*	*Thais lapillus*	*Astarte* spp	*Alaria esculenta*
			Cerastoderma pinnulatum	*Chondrus crispus*
Common and Abundant	INLETS	SUBTIDAL ROCK & GRAVEL	*Crenella decussata*	*Clathromorphum circumscriptum*
			Lunatia heros	*Corallina officinale*
Amphora sp	*Acartia* sp		*Macoma balthica*	*Desmarestia aculeata*
Dinophysis norvegica	*Centropages hamatus*	*Acmaea testudinalis*	*Mya arenaria*	*Fucus* sp
Dinophysis acuminata	*Eurytemora* sp	*Amphipholis squamata*	*Nassarius obsoletus*	*Laminaria longicruris*
Gymnodinium sp	*Microsetella norvegica*	*Asterias vulgaris, A. forbesi*	*Nucula delphinodonta*	*Laminaria digitata*
Licmorphora abbreviata	*Oithona* sp	*Buccinum undatum*	*Placopecten magellanicus*	*Lithothamnion glaciale*
Microflagellates	*Pseudocalanus* sp	*Cancer irroratus, C. borealis*	*Serripes groenlandicus*	*Palmaria palmata*
Navicula sp	*Temora longicornis*	Caprellidae	*Spisula solidissima*	*Phyllophora* spp.
Nitzschia longissima		*Crepidula fornicata*	*Yoldia* sp	*Phymatolithon* sp
Picoplankton	MICROZOOPLANKTON	*Gorgonocephalus arcticus*		*Porphyra linearis*
Pleurosigma strigosum		Green sea urchin	Isopoda	*Ptilota serrata*
Pseudonitzschia delicatissima	*Acanthostomella gracilis*	*Henricia sanguinolenta*	*Idotea* sp	*Sacchorhiza dermatodea*
P. seriata, P. pungens	*Acanthostomella norvegica*	*Homarus americanus*		
Skeletonema costatum		*Hyas* sp.	Cumacea	INTERTIDAL SAND/MUD
Thalassionema nitzschioides		*Ischnochiton rubra*	*Diastylis quadrispinosa*	
		Lacuna vincta	*Diastylis sculpta*	*Cladophora* sp
Occasionally Abundant		*Modiolus modiolus*	*Eudorella* spp	*Enteromorpha* sp
		Mytilus edulis		*Ulva lactuca*
Bacteriastrum elongatum		*Nassarius trivittatus*	Amphipods	
Ceratium longipes		*Ophiopholis aculeata*	*Ampelisca macrocephala*	SUBTIDAL SAND/MUD
Chaetoceros spp		*Pagurus* spp.	*Psammonyx nobilis*	
(C. affinis, C. atlanticus,		*Placopecten magellanicus*	*Unciola irrorata*	*Enteromorpha* sp
C. costatus, C. danicus,		*Psolus fabricii*		*Fucus* sp
C. debilis, C. decipiens,		*Spirorbis* sp.	Polychaetes	*Ulva* sp.
C. laciniosus, C. socialis)		*Tonicella marmorea*	*Arenicola* sp	*Zostera marina*
Cylindrotheca closterium			*Clymenella* sp	
Dinophysis norvegica		SALTMARSH	*Cossura longocirrata*	SALTMARSH
Distephanus speculum			*Glycera* sp	
Euglena sp		*Acteocina canaliculata*	*Nereis* spp	*Enteromorpha* sp
Fragilaria crotonensis		*Capitella capitata*	*Nephtys* spp	*Pennate diatoms*
Gyrosigma balticum		*Corophium* spp	*Nereimyra punctata*	*Ruppia maritima*
Leptocylindrus danicus		*Gammarus* spp	*Ninoe nigripes*	*Spartina patens*
Leptocylindrus minimus		*Gemma gemma*	*Lumbrineris* spp	*Spartina alterniflora*
Melosira sulcata		*Hydrobia totteni*	*Spiochaetopterus* sp	*Ulva* sp
Pleurosigma spp		*Idotea baltica*		
(P. angulatum, P. strigosum)		*Jaera marina*	Decapoda	ESTUARIES
Prorocentrum minimum		*Mitrella lunata*	*Crangon septemspinosa*	
Pseudonitzschia seriata		*Mysella planulata*	*Cancer irroratus*	*Enteromorpha intestinalis*
Rhizosolenia spp		*Mytilus edulis*	*Carcinus maenas*	*Ulva lactuca*
(R. delicatula, R. gracillima,		*Nassarius obsoletus*	*Pandalus* spp	
R. hebetata)		*Nemertea*	*Pagurus* spp.	
Scrippsiella trochoidea		*Orchestia* sp	*Mysis* sp.	
Thalassiosira spp		*Polydora comuta*		
(T. decipiens,		*Scoloplos armiger*	Echinodermata	
T. nordenskioldii, T. rotula)		*Turbonilla interrupta*	*Ophiura robusta*	
Tintinnida			*Ophiura sarsi*	

Sources: Mobil 1983; Dugas and Koslow 1984; Tremblay and Roff 1983; Paranjape et al. 1985; Roff et al. 1986; Conover 1981; R. Scheibling, Dalhousie University, pers. comm.; Thomas 1973, 1978; David Scarratt & Associates 1994 (MS); Head et al. 1994; Keizer et al. 1996; S. Bates, Fisheries and Oceans Canada, personal communication.

1. Common brachyuran larvae include snow crab (*Chionoecetes opilio*), toad crab (*Hyas coarcticus*), Rock crab (*Cancer irroratus*), Jonah crab (*Cancer borealis*) and Green crab (*Carcinus maenas*).

Table 3.3. (continued). Typical biological communities from Nova Scotia inshore coastal waters.

FISH	SEABIRDS	MARINE MAMMALS
ROCKY INTERTIDAL Sculpins (*Myoxocephalus spp*) Tomcod (*Microgadus tomcod*) ROCKY SUBTIDAL Cunner (*Tautogolabrus adspersus*) Dogfish (*Squalus acanthias*) Monkfish (*Lophius americanus*) Rock gunnel (*Pholis gunnelis*) Sculpin (*Myoxocephalus spp*) Snailfish (*Liparis spp*) Thorny Skate (*Raja radiata*) Tomcod (*Microgadus tomcod*) Winter Skate (*Raja ocellata*) Wolffish (*Anarichas lupus*) INTERTIDAL SAND/MUD Atlantic silversides (*Menidia menidia*) Pipefish (*Syngnathus fuscus*) Winter flounder (*Pseudopleuronectes americanus*) SUBTIDAL SAND/MUD Atlantic herring (*Clupea harengus harengus*) Atlantic mackerel (*Scomber scombrus*) Atlantic cod (*Gadus morhua*) Eelpout (*Zoarces viviparus*) White hake (*Urophycis tenuis*) Winter flounder (*Pseudopleuronectes americanus*) INLETS/ESTUARIES Atlantic salmon (*Salmo salar*) Brook trout (*Salvelinus fontinalis*) SALTMARSH Atlantic silversides (*Menidia menidia*) Mummichog (*Fundulus heteroclitus*) Sticklebacks (*Gasterosteus spp*)	INSHORE, COASTAL ISLANDS, ROCKY INLETS Arctic tern (Sterna paradisaea) Black guillemot (Cepphеus grylle) Common eider (Somateria mollissima) Common tern (Sterna hirundo) Diving Ducks Double crested cormorant (Phalacrocorax auritus) Great Black-Back Gull (Larus marinus) Greater cormorant (Phalacrocorax carbo) Herring Gull (Larus argentatus) Osprey (Pandion haliaetus) Roseate tern (Sterna dougallii) INLETS, DEPOSITIONAL ENVIRONMENTS, TIDAL FLATS, SALTMARSHES Canada Goose (Branta canadensis) Diving ducks Great Blue Heron (Ardea herodias) Great Black-Back Gull (Larus marinus) Herring gull (Larus argentatus) Osprey (Pandion haliaetus) Shorebirds (sandpipers, plovers, dowitchers) Terns	COASTAL ISLANDS, INLETS Grey seal (Halichoerus grypus) Harbour seal (Phoca vitulina) Harbour porpoise (Phocoena phocoena)

Sources: Mobil 1983; Dugas and Koslow 1984; Tremblay and Roff 1983; Paranjape et al. 1985; Roff et al. 1986; Conover 1981; R. Scheibling, Dalhousie University, pers. comm.; Thomas 1973, 1978; David Scarratt & Associates 1994 (MS); Head et al. 1994; Keizer et al. 1996; S. Bates, Fisheries and Oceans Canada, personal communication.

3.1.4 Water and Sediment Chemistry

Chemical characteristics of coastal waters and sediments are influenced by local conditions, including the chemical composition of predominant fresh- and seawaters impinging on the coast; types of sediments available through erosion from shore or by transport by coastal currents; organic load and consequent levels of oxygenation; biological activity, including type and degree of development of plant communities and burrowing organisms; and anthropogenic sources. In

general, ocean waters within a few kilometres of the coast are lower in salinity; higher in content of metals and organic contaminants and suspended matter; and higher in nutrients from those found further offshore. Sediments in protected coastal areas (e.g. in bays and inlets) tend to be finer, have elevated organic carbon, and show chemical differences such as elevated metal and organic contents, from those found offshore, and often show evidence of the influence of chemical processes (e.g. enhanced content of some metals) resulting from lowered oxygen concentration. In contrast, coastal areas exposed to the open ocean typically have coarse sand and gravel bottom and are usually lower in content of metals and other contaminants. Chemical processes influencing coastal areas of Nova Scotia have been discussed in *Section 2, Contaminants in Offshore Waters.*

3.1.5 Anthropogenic Influences

The Nova Scotia coastline has been used by humans since the earliest occupation by indigenous peoples. European settlers and their descendants first settled in coastal areas, a trend which continues to the present, the majority of the Nova Scotia population now residing within a few kilometres of the coast. Humans have significantly modified the landscape, by clearing coastal forests for lumber, agriculture, and settlement; constructing infrastructure such as wharves for fishing activity; infilling coastal wetlands such as saltmarshes for coastal development; and altering natural waterways and inlets by landfilling and causeway construction. Activities have contributed to increased sediment loads to coastal areas, and introduced contaminants—arsenic in the case of mining activity; iron from coal mine wastes; heavy metals of all kinds from urban centres; and hydrocarbons from a range of coastal activities—into many coastal areas.

The next sections focus on the problem of coastal contamination on the Atlantic coast of Nova Scotia. They include a detailed discussion of specific harbours which have become concerns because of contamination or degree of development, and include a broad range of coastal environments to provide an overview of characteristics and patterns of chemical contamination which occurs here.

3.2. OVERVIEW OF CONTAMINANTS IN COASTAL AREAS

3.2.1 Introduction

Coastal areas display the major examples of anthropogenic contamination, and, coupled with the importance of these areas for ecosystems and human use, have become the areas of the Scotian Shelf of greatest environmental concern. Contamination is often concentrated near major population and industrial centres—the harbours of Halifax/Dartmouth in mainland Nova Scotia and Sydney on Cape Breton Island (Figure 3.3) rank among the most contaminated inshore regions and Sydney Harbour has some of the highest levels of polycyclic aromatic hydrocarbons (PAHs) in the world.

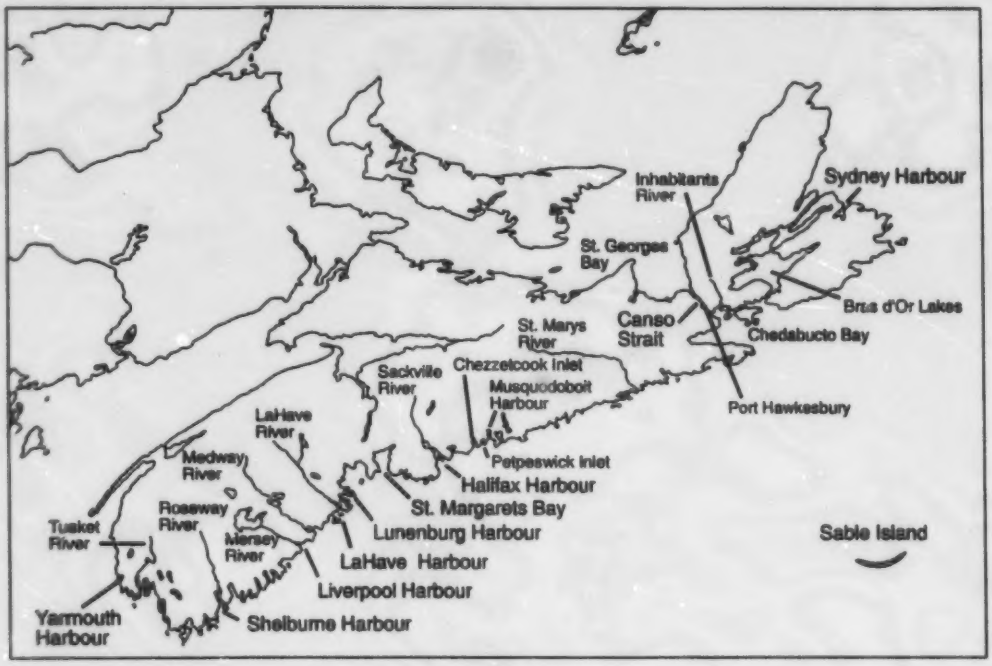


Figure 3.3 Location map for inlets and coastal areas in this report.

Many other ports on the Atlantic coast of Nova Scotia also show significant, though less extreme, examples of contamination. Apart from the most serious cases, a 1985 compilation of contaminant data for harbours requiring dredging in the region showed that perhaps 34 out of 94 (36 %) were 'problem harbours'—that is, defined as contaminated in terms of criteria under the Canadian Ocean Dumping Control Act (ODCA) (now the Canadian Environmental Protection Act, CEPA) (OceanChem Limited 1985) (Figure 3.4). Most were contaminated by cadmium[3] (levels above the ODCA limit of 0.6 μg/g) but several had significant levels of mercury (above 0.75 μg/g), and concentrations of polychlorinated biphenyls (PCBs) (above 100 ng/g). Other

[3] These early cadmium measurements were close to the detection limit of the methods of the era.

studies have shown the potential for contamination of biota, in particular lobsters, from elevated concentrations of polynuclear aromatic hydrocarbons (PAHs) found in many coastal harbours. The lobster fishery in the inner portions of Sydney Harbour was closed because of elevated levels of PAHs found in tissues of that species (Sirota *et al.* 1983; Prouse 1994).

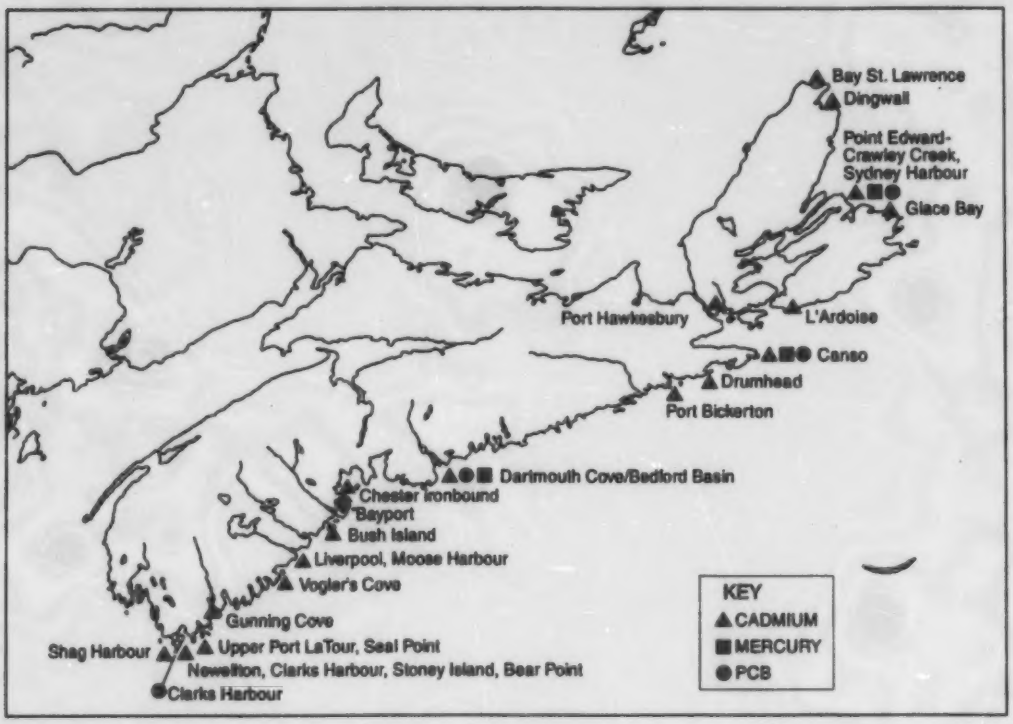


Figure 3.4. Problem harbours for dredging and ocean dumping based on concentrations of cadmium, mercury and PCBs in sediments, which exceeded ocean dumping guideline levels (mercury, 0.75 µg/g; cadmium 0.6 µg/g; PCBs, 100 ng/g) (OceanChem 1985).

Other coastal areas which make up the majority of the coastline, however, include both sites of human activity and development—harbours, fishing and fish plant wharves, industrial locations and sites of residential development typically found along the coast—as well as areas largely free of human interference. No areas, however, are completely free of anthropogenic contamination.

In many cases, research into environmental impacts has focused on problem areas, typically in association with population centres, and only rarely have surveys been conducted of coastal waters of the Atlantic Coast of Nova Scotia to determine distribution of contaminants. Some studies focusing on particular contaminants (e.g. PCBs, Wiltshire 1978; heavy metals, Loring *et al.* 1996; petroleum hydrocarbons in sediments, Levy *et al.* 1988; tributyltin, Hennigar and Garron 1992; pesticides and other contaminants in mussels, Zenon Environmental Inc., 1989MS) have occasionally been carried out. Sediment concentrations of heavy metals including cadmium, copper, lead, mercury and zinc; and organic contaminants PCBs and DDT, have been measured at sites requiring dredging as part of the ocean dumping permitting process (e.g.

OceanChem 1985). These data have generally not been compiled to provide a regional picture of contaminant distribution, and, further, are generally focused on high-activity areas and thus are likely to show extremes of contaminant concentrations. Apart from these studies, there is little information on concentrations of contaminants in water, suspended particulate material, sediments, or marine biota. This section summarizes many of the broader studies, and also those which include some of the less-developed coastal areas on the Atlantic Coast of Nova Scotia.

3.2.2 Chemicals in Water, Sediment and Biota

Water

No information is available on contamination by metals or organic contaminants dissolved or suspended in water in the majority of bays, inlets and estuaries and along the Atlantic Coast of Nova Scotia, although levels have been measured in several studies on the Scotian Shelf (e.g. Cranston and Buckley 1972; Yeats *et al.* 1978; Yeats 1993). Some specific measurements have been made in coastal waters because of pollution concerns (e.g. Halifax Harbour, Dalziel *et al.* 1991; Sydney Harbour, O'Neill and Kieley 1992), and these will be discussed in later sections.

Sediments

Harbours and coastal areas subject to human activity usually have elevated concentrations of contamination by anthropogenic chemicals compared to generally accepted background levels. Loring *et al.* (1996) sampled sediments in ten coastal inlets and estuaries, some of which had experienced relatively little impact of human development (several key inlets, Lunenburg Harbour, LaHave Estuary, Liverpool Harbour, and Shelburne Harbour will be discussed later in respective sections of this report). With the exception of the busiest and most developed harbours, however, most sediments along the Atlantic coast were at or below background levels while cadmium was generally above the background (Figure 3.5; Table 3.4).

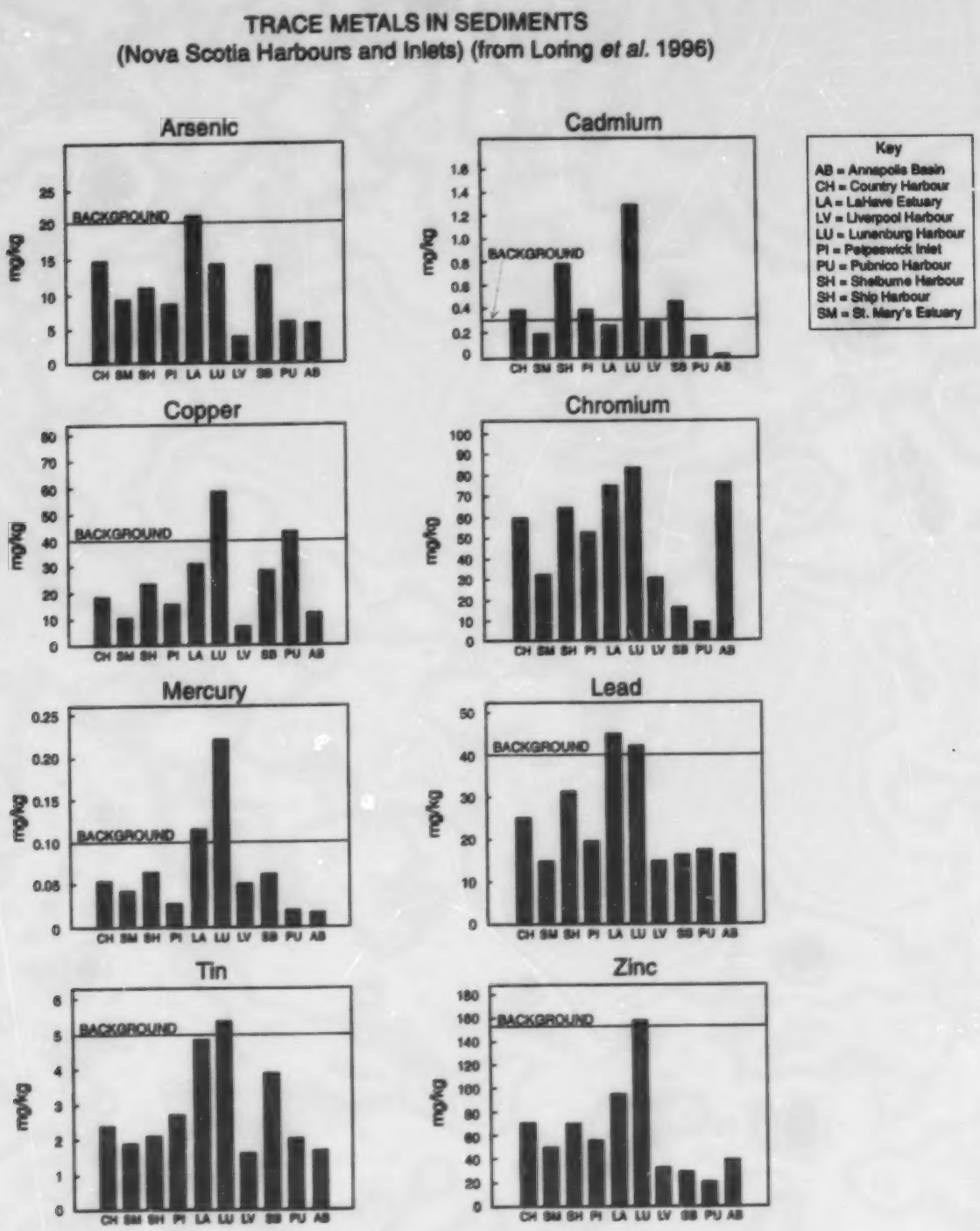


Figure 3.5. Trace metal levels in sediments from selected harbours and inlets on the Atlantic Coast of mainland Nova Scotia (from Loring *et al.* 1996). No background level was determined for Chromium.

Table 3.4. Contaminant metals in assorted inlets on the Atlantic Coast of Nova Scotia (from Loring *et al.* 1996).

Location	Country Harbour	Petpeswick Inlet	Pubnico Harbour	Ship Harbour	St. Mary's River Estuary
Potential Contamination	Gold mining wastes & tailings circa 1900; aquaculture	Cottages and permanent residences	Fish wastes, fishing vessel activity, coastal residences	Residences and aquaculture activities	Agriculture, Town of Sherbrooke, leaching of mine wastes and tailings from circa 1900
Metal	Concentration (ug/g)				
Cadmium	0.41 (0.02 - 0.78)	0.41 (0.03 - 1.22)	0.19 (0.09 - 0.34)	0.81 (0.17 - 2.16)	0.20 (0.03 - 0.56)
Copper	18.1 (8 - 28)	15.7 (6 - 24)	8.9 (7 - 11)	23.3 (13 - 29)	9.6 (4 - 19)
Lead	25.4 (13 - 40)	18.9 (8 - 37)	19.8 (15 - 25)	31.6 (14 - 44)	14.9 (6 - 29)
Mercury	0.05 (0.01 - 0.09)	0.03 (0.01 - 0.07)	0.02 (0.01 - 0.03)	0.06 (0.01 - 0.13	0.04 (0.01 - 0.11)
Zinc	70.2 (32 - 111)	57.4 (20 - 105)	42.3 (30 - 52)	71.0 (32 - 97)	48.6 (20 - 101)

No recent summary of concentrations of key contaminants in sediments sampled for ocean dumping purposes is available, but a compilation by OceanChem (1985) indicated that many of the Atlantic Coastal harbours were contaminated in terms of cadmium and several had significant levels of mercury (OceanChem 1985) (Figure 3.4). Concentrations of PCBs in most of the 20 harbours on the Atlantic coast of Nova Scotia whose sediments were assessed for ocean dumping purposes prior to 1977 ranged from trace to approximately 370 ng/g (Travers and Wilson 1977), the higher concentrations being significantly above background of generally less than 5 to 10 ng/g (see Section 1.3). Seven coastal sites (6 on the Eastern Shore east of Halifax and at Clark's Harbour) gave concentrations in subtidal sediments generally below 5 ng/g, but ranging up to 81 ng/g (Clark's Harbour) (Leonard 1977). In the extreme, PCB concentrations in sediments heavily contaminated by fish plant waste reached more than 20,000 ng/g dry weight near a fish processing operation at Petit-de-Grat on Isle Madame in Chedabucto Bay (Ernst *et al.* 1982).

There are no summaries or recent compilations of DDT concentrations in sediments. A sampling of the seven sites on the Eastern Shore and at Clark's Harbour noted above, gave concentrations generally below 1 ng/g, with highest levels (9 to 20 ng/g) at Clark's Harbour (Leonard 1977). The levels are above the Canadian interim sediment quality guideline for total DDT in sediments of 3.89 ng/g (Environment Canada 1995) (a guideline for total DDT (DDT and metabolites) is not provided in the current Canadian interim sediment quality guidelines, CCME 1999).

Levels of petroleum hydrocarbons in Nova Scotia coastal sediments vary widely, although ranges of 5 to 405 μg/g of wet sediment (Hargrave and Phillips 1975) and 0.24 to 376.5 μg/g (Levy *et al.* 1988) have been reported in surveys of coastal areas. Coastal harbours in areas not supporting oil refineries, industrial activities, and major population centres, however, generally

have low concentrations of petroleum hydrocarbons in sediments, mostly averaging below 10 μg/g (Levy *et al.* 1988) (Figure 3.6).

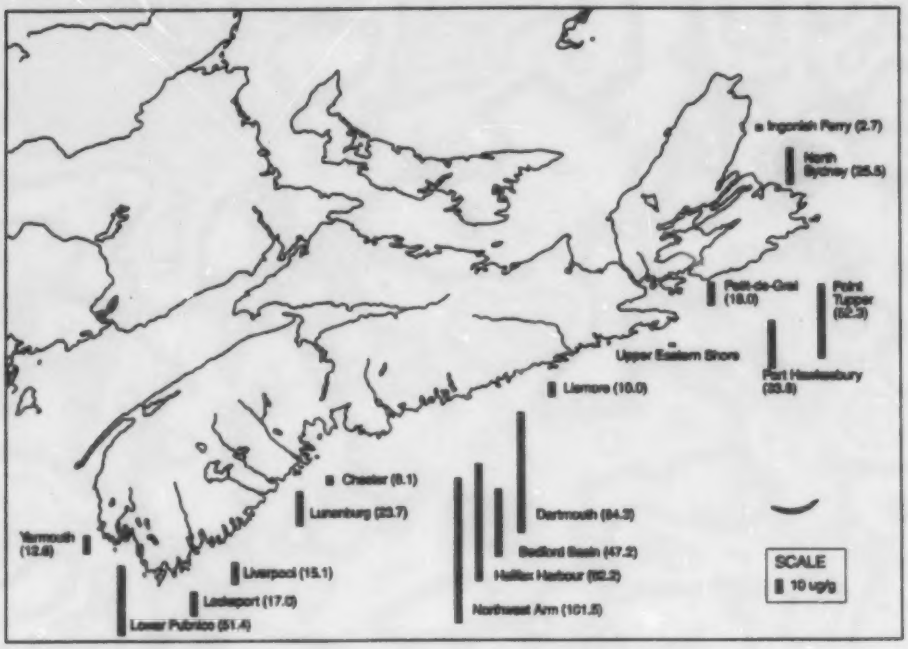


Figure 3.6. Average concentration (μg/g) of petroleum residues in harbour surficial sediments (from Levy *et al.* 1988; OceanChem 1985).

Biota

There is little information of any kind on concentration and distribution of contaminants in biological tissues in harbours and coastal areas of the Atlantic coast of Nova Scotia. Several studies in the 1970s which examined mercury, cadmium and arsenic concentrations in shellfish and eels in the Maritime provinces, showed low concentrations of mercury, typically less than 0.01 μg/g in clams, mussels and oysters collected throughout the Maritimes (Wilson and Travers 1977), while content of mercury in eels ranged from 0.02 to 3.5 μg/g and averaged 0.5 μg/g for Nova Scotia and the New Brunswick Fundy coast (Freeman and Horne 1972 from Wilson and Travers 1977).

Cadmium concentration in lobster digestive gland at various locations in Atlantic Canada was assessed in the 1970s because of concern over concentrations of the metal in lobster paste (Uthe and Freeman 1980). Levels at several sites on the Atlantic coast of Nova Scotia (Table 1.5) were far below the peak of 500 μg/g which led to closure of a lobster fishery in Belledune, New Brunswick in the late 1970s, and would correspond to levels in lobster tail muscle below the 2 μg/g wet weight guideline for human consumption of fish tissue (Health and Welfare Canada Guidelines) (Freeman and Uthe 1974). Lobster in several coastal areas of the eastern shore of Nova Scotia at the time had elevated levels of arsenic in digestive glands (ranging from 8.7 to 16.2 μg/g wet weight), compared with the Gulf of St. Lawrence (range 5.9 to 10.6 μg/g wet weight) (Table 1.5) (Freeman and Uthe 1974), but the cause of the difference was not

determined. No more recent measurements of metals in lobster are available, except in Halifax Inlet, where elevated concentrations in lobster digestive gland occur as a result of local contamination (See Section 3.3, *Halifax Inlet*).

Concentrations of polycyclic aromatic hydrocarbons (PAHs) in lobster digestive gland have been measured at various coastal sites in Eastern Nova Scotia and Cape Breton, to provide comparative values in connection with studies of contamination by these compounds in lobsters from Sydney Harbour, and to assess the impacts of *Kurdistan* oil spill in 1979 (Figure 1.2). These results are presented in discussions of PAHs in lobster found in Sections 3.4.5 and 3.5.5.

Environment Canada also found various contaminants in mussels from one undeveloped site (Beaver Harbour) along the Eastern Shore of the Nova Scotia Atlantic Coast, in 1989 (Zenon Environmental Inc. 1989MS) (Table 3.5). Concentrations of key trace metals (allowing for wet/dry weight measurement differences) were comparable for lead, and higher for arsenic, cadmium, chromium and mercury, to averages for mussels in United States coastal areas, and in the Gulf of Maine (O'Connor 1992; GMCME 1994) (See Table 1.4). The plasticizers bis (2-ethylhexyl) phthalate and di-n-octyl phthalate were present in the mussels, and key PAHs were below 100 ng/g or not present. A scan of pesticides and aromatic amines detected only the carboxylic acid pesticide picloram, a brush-control agent, at concentrations less than 0.05 μg/g wet weight (Zenon Environmental Inc. 1989MS).

Table 3.5. Concentrations of contaminants found in mussels from selected sites along the Atlantic Coast of Nova Scotia, in a survey of metals, volatile and semi-volatile organics, PAHs, chlorinated organics, pesticides and aromatic amines carried out by Environment Canada. Only contaminants which were detected are presented (Zenon Environmental Inc. 1989MS; G. Julien, Environment Canada, Personal Communication.

Contaminant	Concentration (ug/g wet weight)		
	LaHave	Lunenburg Harbour	Beaver Harbour
Metals			
Arsenic	0.48 ug/g	1.8 ug/g	1.6 ug/g
Cadmium	0.27 ug/g	0.26 - 0.75 ug/g	2.1 ug/g
Chromium	0.29 ug/g	0.26 - 0.49 ug/g	0.48 ug/g
Copper	1.3 ug/g	1.2 - 2.3 ug/g	1.2 ug/g
Iron	90 ug/g	100 - 130 ug/g	120 ug/g
Lead	7.9 ug/g	less than 0.5 - 1.2 ug/g	less than 0.5 ug/g
Mercury	0.040 ug/g	0.036 ug/g	0.064 ug/g
Silver	less than 0.3 ug/g	less than 0.3 ug/g	less than 0.3 ug/g
Zinc	22 ug/g	16 - 19 ug/g	11 ug/g
Organics			
bis(2-ethylhexyl) phthalate [1]	not detected	0.44 ug/g	not detected
di-n-octyl phthalate [1]	0.28 ug/g	0.12 ug/g	0.53 ug/g
methylene chloride	0.063 ug/g	0.074 ug/g	not detected
carbofuran [2]	not detected	less than 0.1 ug/g	not detected
picloram [3]	less than 0.03 ug/g	less than 0.05 ug/g	less than 0.05 ug/g
Selected PAHs benzo(a)anthracene benzo(a)pyrene fluoranthene pyrene triphenylene	none detected (detection limit, < 0.1 ug/g)	none detected (detection limit, < 0.1 ug/g)	none detected (detection limit, < 0.1 ug/g)
1. plasticizer; 2. nitrogen/phosphorus pesticide; 3. carboxylic acid pesticide.			

3.3 HALIFAX INLET

Halifax Inlet is the location of the main port and largest concentration of population on the Nova Scotia Atlantic Coast (combined populations of the cities of Halifax, Dartmouth and the Town of Bedford of 193,865, 1991 census) (Figure 3.7). The Inlet has a long history of development as one of the oldest urban centres in Atlantic Canada. The accumulated releases of industrial wastes and sewage in particular as well as other wastes have led to significant metal and organic contamination of harbour sediments, ranking Halifax Inlet as one of the most contaminated harbours in Nova Scotia, and comparable to many major harbours around the world.

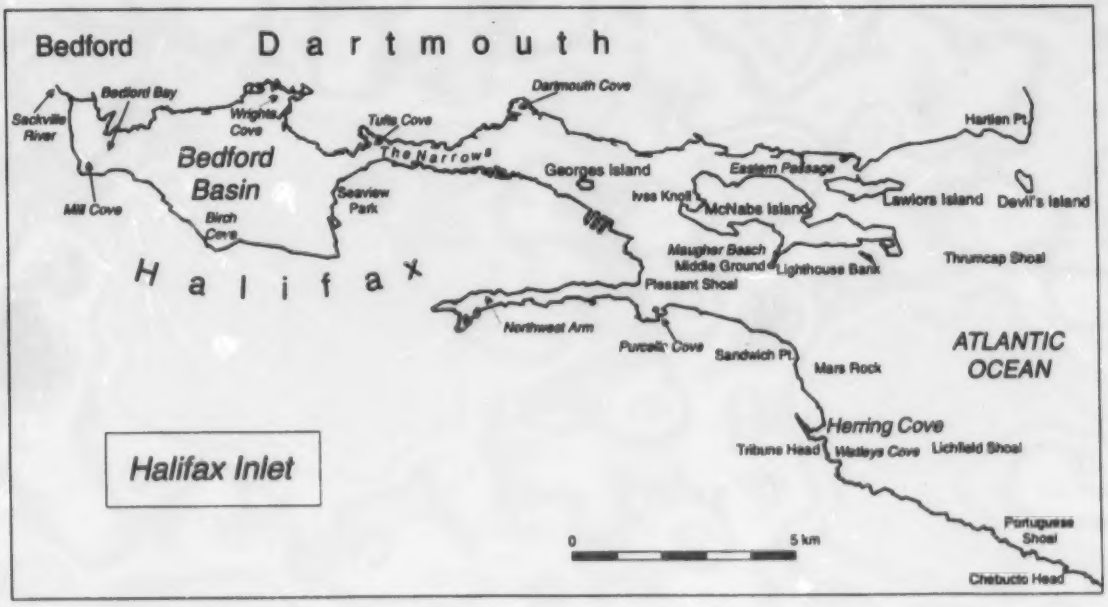


Figure 3.7. Halifax Inlet and key points of reference.

3.3.1 Oceanography

Halifax Inlet has been characterized as a perfect harbour, about 25-km long and relatively narrow, but having a 70-m deep, roughly circular basin (Bedford Basin) on its inner (northern) end. The basin is separated from the central harbour by a narrow (0.4-km) channel (The Narrows) which shallows to less than 20 m at its inner end. The harbour widens and deepens towards the mouth, reaching depths up to 37 m. A narrow inlet (Northwest Arm) joins the outer reaches of Halifax Inlet, and reaches a maximum depth of 25 m (Figures 3.7 to 3.9).

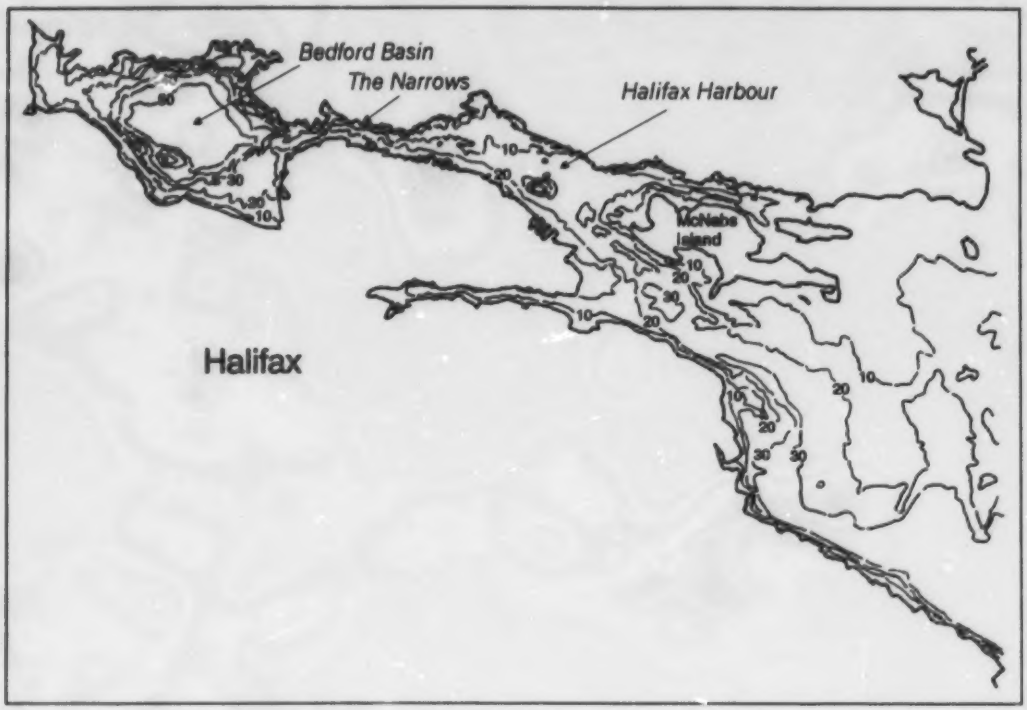


Figure 3.8. Depth contours (metres) of Halifax Inlet.

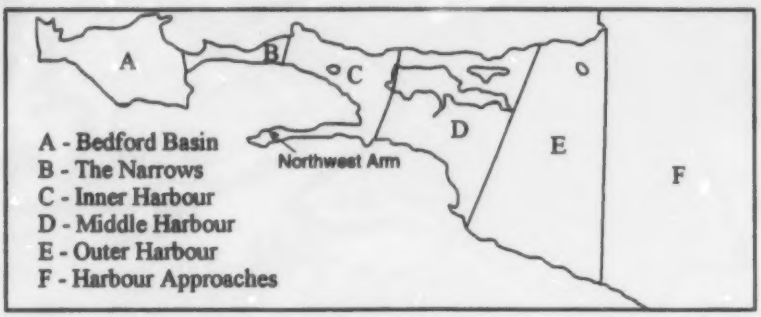


Figure 3.9. Divisions of Halifax Inlet.

A watershed of 480 square kilometres provides a freshwater inflow to Halifax Inlet of 17.6 cubic metres per second (Gregory *et al.* 1993). The Sackville River is the largest freshwater source, having an average flow of 5.4 cubic metres per second (ranging from 2 in summer to 9 in spring). Other, smaller, freshwater sources, each generally less than about 1 cubic metre per second, account for approximately 7.8 cubic metres per second, while sewage discharge (not including storm runoff) adds from 2.1 to 2.5 cubic metres per second (some 40 million Litres per day) to the inlet (Buckley and Winters 1992; Petrie and Yeats 1990).

Circulation in Halifax Inlet is generally three-layered and estuarine, owing to freshwater flow of the Sackville River at the surface; a return flow at mid-depth; and a deep near-bottom layer in

Bedford Basin which shows little flow. The surface layer outflow consists of water of reduced salinity (typically from less than 28 to 30 ppt in winter and 30 - 31 ppt in summer), while the subsurface inflow consists of deeper, colder, and high salinity water (30 - 31 ppt, Petrie and Yeats 1990) (Figure 3.10). The salinity of the surface layer is typically about 0.5 to 2.5 ppt less than that of the deeper water (Buckley and Winters 1992). Passage of weather systems and associated winds reinforce the estuarine circulation (Petrie and Yeats 1990).

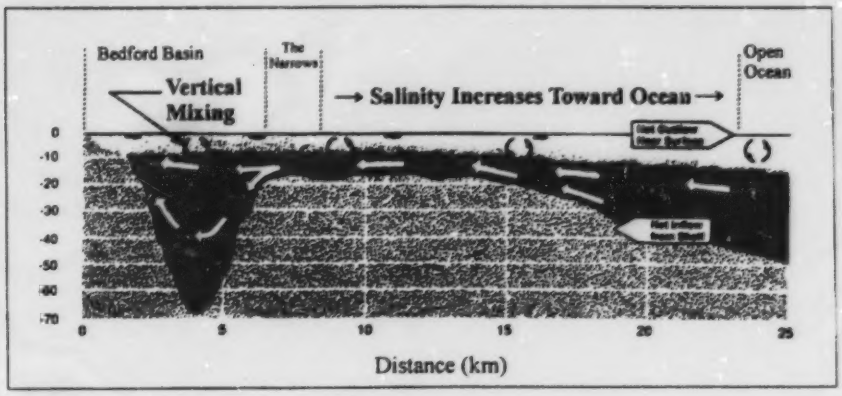


Figure 3.10. Circulation patterns in Halifax Inlet (from Halifax Harbour Task Force 1990).

Average currents are generally weak and variable, affected by tidal, estuarine and atmospheric influences. Weakest average currents occur in Bedford Basin, and the strongest occur in the Narrows, where surface outflow is from 1.6 to 2.4 cm/s and incoming bottom currents from 0 to 6 cm/s (Petrie and Yeats 1990). Tidal currents in the Narrows can be significant, frequently exceeding 25 cm/s (0.9 km/hr) (Halifax Harbour Task Force 1990) and tidal excursion (the distance travelled by a particle of water during a tidal cycle) can reach 3.3 kilometres (Lawrence 1989). Tides are semi-diurnal (twice a day) with a mean tidal range of 1.6 metres (Gregory *et al.* 1993).

Many factors contribute to the exchange and replenishment of water in the Inlet with water from offshore. These vary in magnitude, space and time, and consequently a wide range of estimates of flushing time for the upper 20 metres have been made (4.3 to 83 days), depending on weather and season, as well as on estimation technique used (Lawrence 1989; Gregory *et al.* 1993). Flushing is particularly influenced by wind conditions; prolonged west and southwest winds can cause rapid replacement of the surface stratified layer in Bedford Basin (in as little as 5 days or less (Lewis and Platt (1982) in Lawrence (1989)). Bottom water in Bedford Basin is replenished periodically by oceanographic events which force intrusions of dense, subsurface water from offshore through the Inner Harbour and over the sill (an area of shallow water separating two deeper areas) at the Narrows (Platt *et al.* 1970; Lawrence 1989). Replacement can be so infrequent that near-bottom waters in Bedford Basin can develop low oxygen conditions and in extreme cases become anoxic (Platt *et al.* 1970).

The waters of Halifax Inlet are underlain by a wide range of sediments, whose characteristics depend mainly on the kinds of source material, on wave and current activity, and on human influence (e.g. input of sewage). Where bottom currents or wave energy are strong, such as in the Narrows and approaches and in nearshore areas, the seabed consists predominantly of sand and

gravel and occasional bedrock. The southern part of the central harbour is covered by extensive areas of mud with some isolated patches and knolls of gravel-covered till. Sediments near sewer outfalls frequently are relatively fine, having an enriched content of organic carbon (Buckley and Winters 1992). Silt with high proportions of both sand and clay is the predominant surface sediment in Bedford Basin, which frequently has gas-charged pockets, and patches of coarse debris from dredge spoils scattered throughout.

3.3.2 Biology

The marine biological community of Halifax Inlet is productive and diverse, typical of north temperate marine areas and in common with other coastal areas on the Atlantic coast of Nova Scotia (see Table 3.3). The spring bloom of phytoplankton (predominantly diatoms) occurs in the February to April period in response to the onset of warming and stratification of the surface waters. Additional blooms may also occur in late spring and early summer (Hargrave 1979; Niven *et al.* 1995) in some cases when storms have broken down stratification and it has been restored again (Figure 3.11). A 'fall bloom' occurs late in the year associated with upward mixing of nutrients as the water column becomes less stable and the mixed layer deepens (Platt *et al.* 1970). Typical phytoplankton species in the spring bloom in Bedford Basin are diatoms, *Chaetoceros concavicornis*, *C. socialis*, *Skeletonema costatum*, *Fragilaria crontonensis*, *Thalassiothrix nitzschioides*, *Coscinosira polychorda*, *Thalassiosira decipiens*, *T. nordenskioeldii*, and *Nitzschia delicatissima* (Head *et al.* 1994). Primary production of phytoplankton in Bedford Basin is relatively high, estimated at about 200 grams carbon per square metre per year and comparable to St. Margaret's Bay (Taguchi *et al.* 1975; Marine Ecology Laboratory 1980). Typically most of the production by phytoplankton is consumed by animals in the upper stratified layer; 10-20% settles to the bottom (Hargrave 1979).

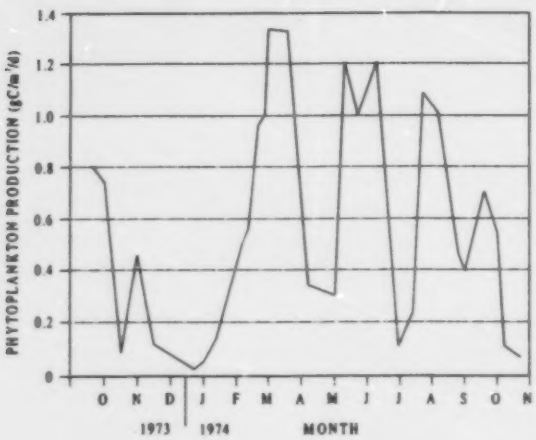


Figure 3.11. Seasonal fluctuations in primary productivity in Bedford Basin in 1973-74 (redrawn from Hargrave 1979).

Most of Halifax Inlet has a rocky coastline suitable for seaweeds, which are both common (found widely) and abundant (occurring in great numbers) but little studied. Many of the species are those commonly found elsewhere on rocky shores of the Atlantic Coast (Table 3.3, Section 3.1.3) (Moore and Miller 1983; Hargrave *et al.* 1989; Halifax Harbour Task Force 1990). Communities of seabed invertebrate organisms are, for the most part, typical of the Atlantic coast (Table 3.3, Section 3.1.3) (see also Hargrave *et al.* 1989; Halifax Harbour Task Force 1990), but the deep portions of Bedford Basin have animal assemblages characteristic of soft, highly organic sediments which occasionally are subjected to low oxygen concentrations. There, the abundance and diversity of organisms is low (2 to 7 species), dominated by polychaete worms and burrowing anemones. The dominant polychaete in the deep bottom of Bedford Basin is

Spiochaetopterus sp., but others include *Nereimyra punctata*, *Ninoe nigripes*, and *Cossura longocirrata* (Platt *et al.* 1970; Hargrave *et al.* 1989; Peer *et al.* 1989). In shallower waters in Bedford Basin, diversity and biomass is higher, typically up to 16 species and 152 grams per square metre or more (Hargrave *et al.* 1989).

A range of fish species occurs in Halifax Inlet but commercial fisheries (except for lobster) are carried out only seaward of the Halifax/Dartmouth waterfront (Ducharme 1989). In addition to the occurrence of marine species such as cod, herring, haddock, mackerel, pollock and flatfish, minor runs of anadromous species (gaspereau and salmon) occur in the Sackville River (Halifax Harbour Task Force 1990).

Marine mammals may occur in the outer harbour, including fin, right, sei, minke, pilot and occasionally beluga whales, and common and white-sided dolphins and harbour porpoise visit in summer and fall, but no resident populations occur. Harbour and grey seals may occur throughout the Inlet (Halifax Harbour Task Force 1990).

3.3.3 Fisheries

Halifax Inlet supports several recreational and commercial fisheries, the latter employing up to 100 people full or part-time (Halifax Harbour Task Force 1990). Handlining for cod, haddock and occasionally mackerel, a cod net fishery in summer, and a herring net fishery from February to September take place along the Western Shore of the outer harbour, while net fisheries for cod, haddock and herring are important on the northeast approaches to the Inlet, south of Thrumcap Shoal (southeast of McNab's Island) (Ducharme 1989). Lobster are fished throughout the Inlet—more than 5,000 lobster traps are set each year. Recreational fishing for Atlantic salmon and gaspereau takes place at the mouth of the Sackville River (Ducharme 1989; Prouse 1994).

3.3.4 Anthropogenic Sources of Chemicals

Halifax Inlet has been the receiving water for a wide range of contaminants arising from domestic and industrial activity since its founding in 1749. Although it supports a small population, the Inlet is a major shipping port; a centre of military, ship-building and repair activity; a fishing port and location of marinas and other boating facilities; the site of an oil refinery (two until recently) and a thermal power plant; and a concentration of various light industries, which traditionally have added a wide range of contaminants.

Raw sewage and storm runoff from the cities of Halifax and Dartmouth are a major source of contamination. Currently about 100 million litres of untreated sewage and industrial wastes are released into the Harbour daily (Halifax Harbour Task Force 1990). In addition to these 'point sources' of contamination, other factors of broader impact ('non-point' sources such as natural runoff and deposition of dust, acid rain, and other air pollutants), as well as inputs due to activities such as coastal landfilling and careless disposal of refuse and litter, can also have a significant impact on conditions. Taken together, these activities have, over a long period, brought significant changes to the character of Halifax Inlet, as well as introducing a broad spectrum of anthropogenic contaminants.

SEDIMENT CHEMISTRY PROVIDES CLUES TO SOURCES OF CONTAMINANTS IN HALIFAX INLET

The most important sources of contaminants, as well as the major processes affecting contaminant distribution in Halifax Inlet have been determined indirectly from studies which analyzed the geochemical and contaminant characteristics of sediments (Buckley *et al.* 1995; Buckley and Winters 1992).

Sewage is the main source of trace metals and organic carbon in Halifax Inlet sediments, the concentrations of both of which are elevated in the vicinity of major sewage outfalls. The effluent carries of a load of metals, but in addition the organic matter in the sewage binds dissolved metals from the water column, and carries them to the bottom, enriching bottom sediments with metals from both these sources when it settles. Most metals tend to stay in the sediments because low oxygen concentrations caused by oxygen demand of the organic matter, favours keeping them in insoluble states. As a result, concentrations of total zinc, copper, lead, cadmium and mercury in sediments are 1.4 to 1.7 times greater, and organic carbon 1.3 times greater near sewage outfalls, than the average for Halifax Inlet as a whole (Buckley and Winters 1992). Sewage outflows affect a significant proportion, about 13% (2.75 km^2), of the Inlet (Figure 3.12).

Natural inflows of water from the main surface drainage systems (rivers and streams) and stormwater outflows, carry fine particulate material which settles near the source to form sediments having characteristic contaminant concentrations and physical features. These sediments have high concentrations of aluminum, magnesium, potassium, lithium, and iron (enriched by about 1.2 times over those of the rest of the harbour), and a high clay content. These sediments are found over 22% of the Inlet, principally near the head of Bedford Basin, associated with the Sackville River outflow.

Leaching of metals from the abandoned Halifax City dump on Bedford Basin, and activities associated with a shipyard and naval dockyards and facilities on the Halifax waterfront, have led to distinctive localized distributions and concentrations of metals in sediments in their proximity (Figure 3.12). In these sediments, fewer of the metals are in forms which are likely to be bound to organic matter, indicating that they deposited in conditions where oxygen was present at the time of deposition (unlike the metals depositing from sewage, in which oxygen concentration is frequently low). Surface sediments having elevated concentrations of similar characteristic forms of metals, also occur in other parts of the harbour, where the elevated metal concentrations are believed to result from metals in dissolved form moving up through the sediment column from more contaminated layers below, and precipitating at the surface. Areas having these characteristics account for 26% of Halifax Inlet sediments.

There are also sites of localized contamination, likely reflecting accidental releases—dumping of garbage, used paint, chemicals etc.. For example, elevated calcium concentrations are found in sediments in the vicinity of a gypsum loading pier on Bedford Basin, reflecting accidental dumping of that mineral (calcium sulphate—CaSO4); while elevated calcium in sediments in Tufts Cove adjacent to the thermal generating plant on the Halifax Narrows may indicate the presence of calcium sulphate, formed as the result of releases of calcium from periodic flushing of components of the plant cooling system (Buckley and Winters 1992). High levels of mercury near the main sewage outfall on the Halifax waterfront, has been suggested to have arisen from laboratories in the six hospitals and two universities which use that part of the sewer system. Finally, a high lead concentration and elevated metals near the Dartmouth Shipyards in Dartmouth Cove, was suspected to be due to the presence in sediments of residues of lead-based paint, commonly used in local marine industries up to the late 1960s (Buckley and Winters 1992).

Several areas having sediments with characteristically elevated concentrations of manganese but low levels of other metals occur in Bedford Basin and in the outer harbour. These sites represent places where naturally-occurring manganese from sediments dissolves due to anoxic conditions, and moves to the surface. There, in the presence of oxygen, it precipitates, leading to elevated concentrations at the sediment surface. These areas apparently represent relatively uncontaminated sediments and occupy about 45% of Halifax Inlet sediments.

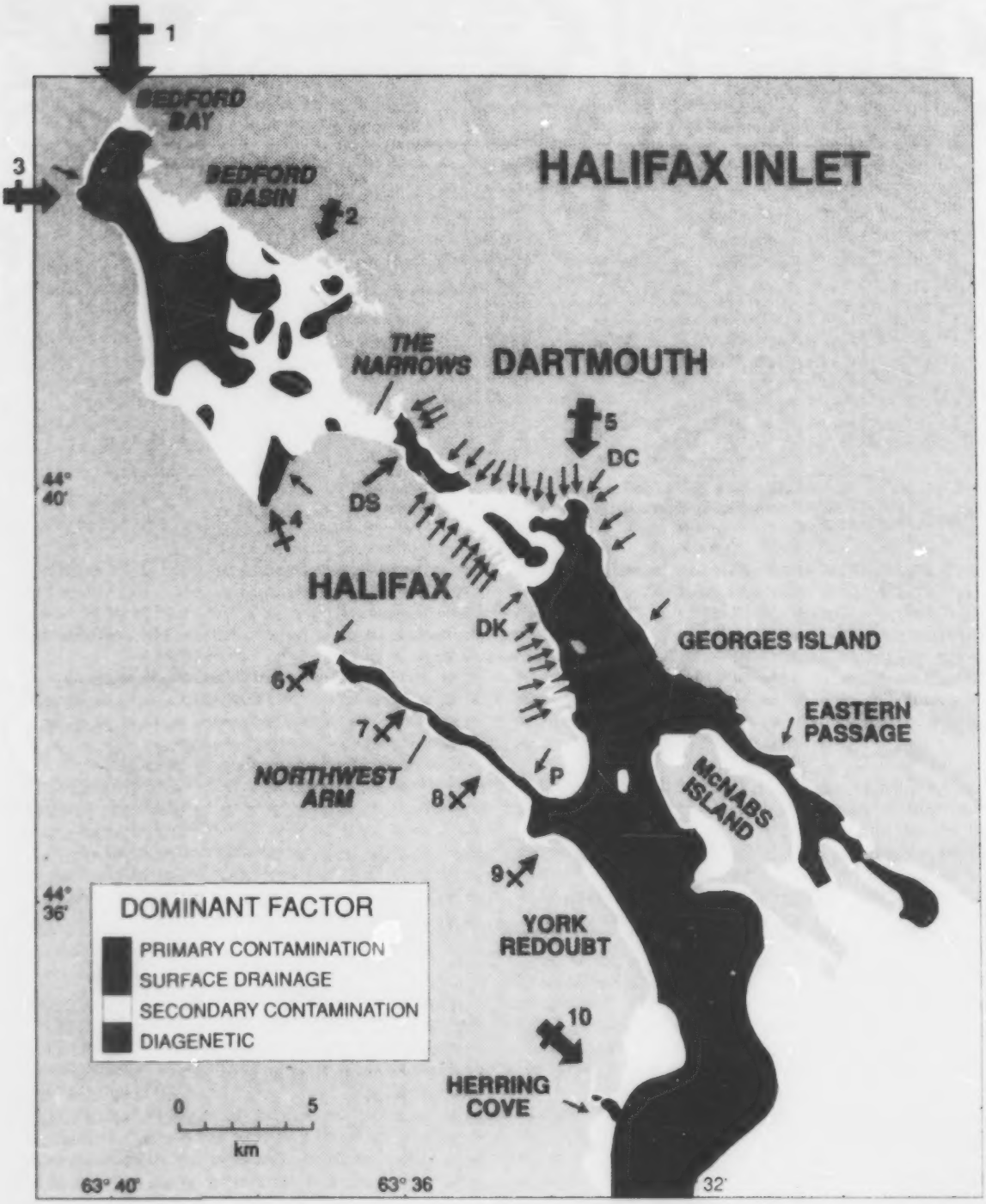


Figure 3.12. Distribution of dominant factors in contamination of sediments in Halifax Inlet (from Buckley and Winters 1992).

THE CHANGING FACE OF HALIFAX INLET CONTAMINATION

The pattern of changing human activity and release of contaminants into Halifax Inlet in the past 250 years of human occupation, has been profiled by several studies which looked at changing concentrations of contaminants (metals, petroleum hydrocarbons and polycyclic hydrocarbons (PAHs)) at successive depths in bottom sediments. Using estimates of the date of deposition and contaminant concentration for layers in the sediments, and a statistical approach known as factor analysis, it has been possible to identify patterns of contaminant distribution and other sediment characteristics among many points in the inlet at different times in the past, and so determine the contaminant sources (e.g. sewage pollution) which were most important at different times (Buckley *et al.* 1995; Buckley and Winters 1992; Gearing *et al.* 1991).

Inferences from Metal Distributions

The relative influence of each of the most important contaminant sources (or factors) has changed over time, and differs depending on the location in the Harbour (Buckley *et al.* 1995) (Figure 3.12). Each part of Halifax Inlet shows different profiles of metal concentration with depth in sediment cores. This is illustrated by the distribution of copper in sediments (Figure 3.13).

At the head of the Inlet (Bedford Bay) and in most of Bedford Basin, contamination arising from sewage and industrial development has not been a major factor in the chemical profile, and the influence of sedimentation of material from freshwater runoff has been the predominant influence from about 1840 to the present (Table 3.6). From 1968 to 1978, the analysis detected natural processes in the upper levels of the sediment, in which dissolved metals released from sediments precipitate in oxygenated conditions at the surface. More recently, metals leached from an abandoned city dump on the shore, and subsequently deposited in nearby sediments, became important on the margin of Bedford Basin, as shown by the analysis.

In the central Inlet (the area of heavy industrial and commercial activity, as well as the site of many sewer outfalls), natural processes dominated up to 1900 after which contamination from sewage and industrial wastes increased in importance and predominated until about 1960, a period which corresponds to a time of military and industrial expansion of the Port of Halifax. Between 1960 and 1972, the dominant influences were natural processes involving movement of metals in dissolved form to the surface layers—enriching concentrations there—and surface runoff, which added metals to sediments. After 1972, sewage and industrial contamination dominated again, likely as a result of the rapidly expanding population.

In the Northwest Arm, sediments were first dominated by surface drainage influences until about 1916 after which primary contamination (sewage) and secondary contamination (anthropogenic releases from other sources) became important, incidentally coinciding with a time when a major sewer outfall was placed at the entrance to the Arm (Buckley *et al.* 1995).

Inferences from Organic Contaminants in Sediments

In the Northwest Arm, organic contaminants including PAHs and petroleum hydrocarbons have been measured at various depths in the sediment column, giving further insight into sources and patterns of contamination in the area (Gearing *et al.* 1991). Petroleum hydrocarbon concentrations decrease from the surface (post-1910) to deeper in Northwest Arm sediments, reaching relatively stable levels (100-fold lower than in most recent times) in the pre-1880 period. PAHs follow similar patterns, showing high concentrations in the post-1900 period and lower levels in the deeper (earlier) sediments, but peak in the 1940-1960 period (Figure 3.14). The source of the PAHs is principally the combustion of fuels (indicated by the prevalence of certain types of PAHs), and the pattern of distribution in sediments is believed to show a shift in burning practices away from wood and coal in the post-1960 era (Gearing *et al.* 1991).

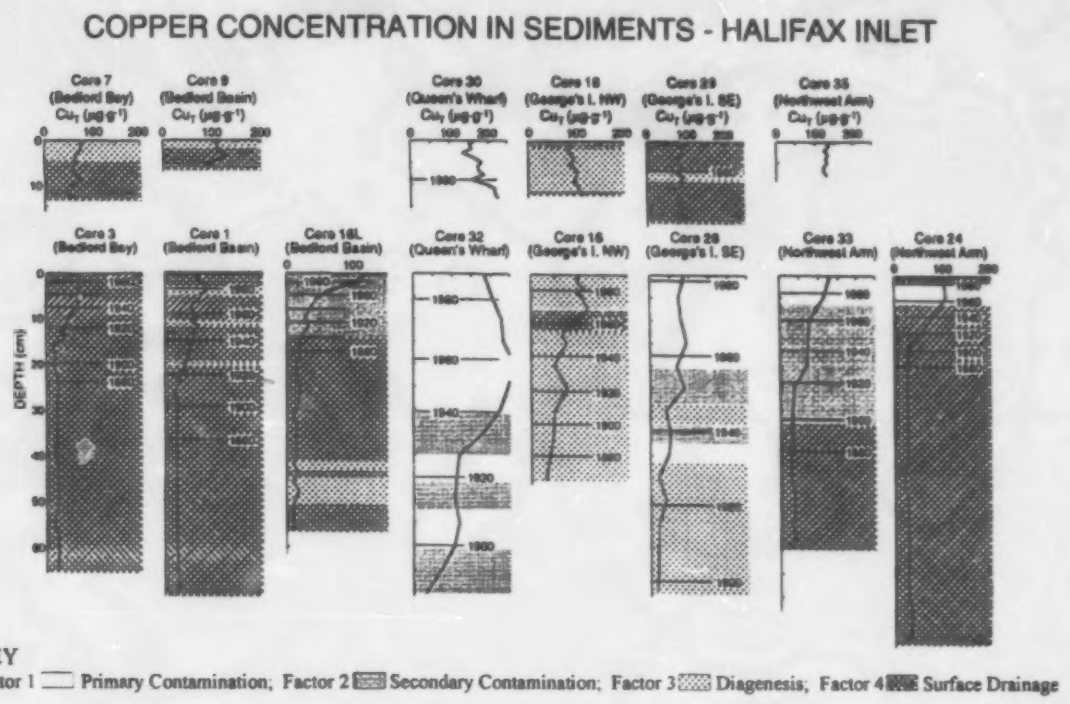

COPPER CONCENTRATION IN SEDIMENTS - HALIFAX INLET
Core 7 (Bedford Bay)
Core 9 (Bedford Basin)
Core 30 (Queen's Wharf)
Core 18 (George's I. NW)
Core 29 (George's I. SE)
Core 35 (Northwest Arm)
Core 3 (Bedford Bay)
Core 1 (Bedford Basin)
Core 16L (Bedford Basin)
Core 32 (Queen's Wharf)
Core 16 (George's I. NW)
Core 28 (George's I. SE)
Core 33 (Northwest Arm)
Core 24 (Northwest Arm)
DEPTH (cm)
KEY
Factor 1 Primary Contamination; Factor 2 Secondary Contamination; Factor 3 Diagenesis; Factor 4 Surface Drainage

Figure 3.13. Profiles of copper concentration in sediment cores from Halifax Inlet, illustrating historical patterns of contamination (from Buckley *et al.* 1995). In core 16L (Bedford Basin) the concentration of copper was low until about 1900 and then rose abruptly to present. In core 32 (Queen's Wharf), the concentration of copper in sediments peaked about 1960.

Table 3.6. Spatial and temporal trends of contamination in Halifax Inlet, 1840 to present.

Location in Halifax Inlet	Direct Sewage Contamination (Primary Contamination)	Contamination from Landfill and Industry (Secondary Contamination)	Diagenetic Processes [1]	Runoff
Bedford Basin	minor	mid-1980s	1968-1978	1840-1970 1978-present
Central Harbour	1900-1960 1972-present	1900-1960	1840-1900 1960-1972	
Northwest Arm	1970-present	1916-1970		1840-1916

1. biological, chemical and physical processes that alter sediment characteristics over time.

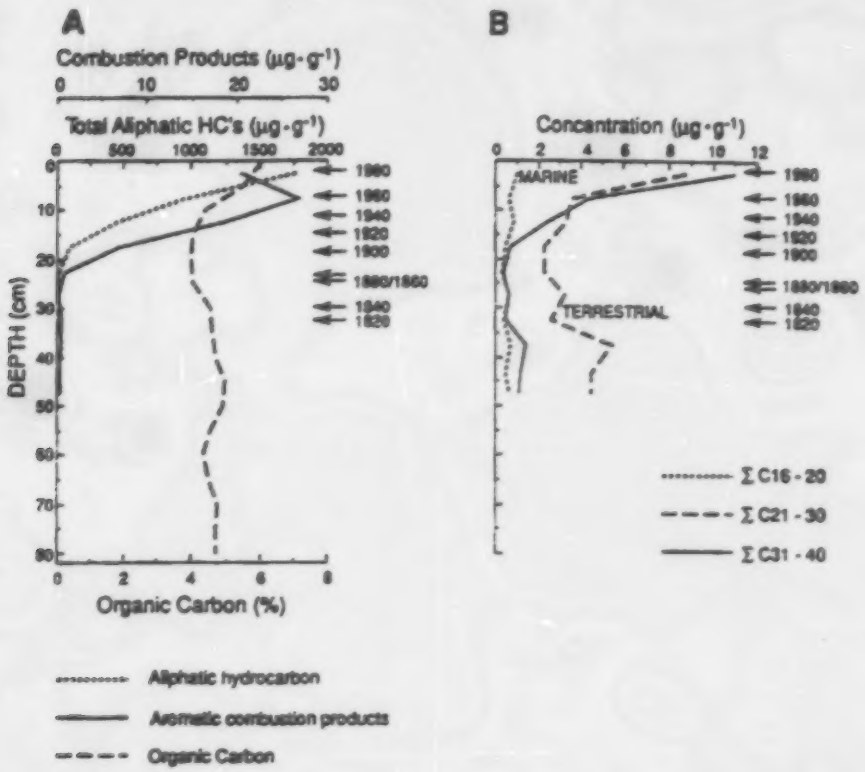


Figure 3.14. Profiles of: (A) total aliphatic hydrocarbons, combustion products, and total organic carbon; and (B) n-alkanes in a sediment core from Northwest Arm, illustrating historic patterns of contamination (from Gearing *et al.* 1991). Aliphatic hydrocarbons are those derived from fossil fuels and products (gasoline, oil, grease, etc.) while aromatic combustion products refer to PAHs.

3.3.5 Occurrences of Chemicals in Water, Sediments and Biota

Halifax Inlet has comparable levels of contaminants to other major North American ports, reflected in high levels of trace metals, and organic contaminants, including PAHs and hydrocarbons, in sediments. In addition, elevated levels of particulate and dissolved metals and hydrocarbons occur in Halifax Inlet waters, while significant concentrations of various contaminants occur in biological organisms; metals, PAHs and PCBs in lobster, and metals and other organic contaminants for mussels. The dynamics of contaminants in the Inlet are influenced both by anthropogenic factors such as the degree of sewage contamination and local use of fossil fuels, as well as by naturally-occurring processes which have been acting in the area for centuries. Levels of contaminants in waters, sediments and the biota of Halifax Inlet are discussed in the following sections.

Water

Levels of chemical contaminants in water have been measured occasionally in Halifax Harbour, including an in-depth study over one year of dissolved and particulate metals (Dalziel *et al.*

1991); and a survey of dissolved petroleum hydrocarbons in the mid-1970s (Gordon *et al.* 1978). Dissolved metal concentrations are relatively low, although above those on the Scotian Shelf, which can be considered to have background levels. Generally Halifax Inlet levels were twice the Scotian Shelf concentrations, but zinc, which had some anomalously high values (e.g. Dartmouth Cove) had average concentrations 4 to 5 times higher (Dalziel *et al.* 1991) (Table 3.7, Figure 3.15). These levels are well below guidelines for protection of marine aquatic life (McNeely *et al.* 1979), but their elevation relative to other waters demonstrates significant contamination.

Table 3.7. Dissolved metal concentrations in Halifax Harbour (from Dalziel *et al.* 1991)

Metal	Concentration (ug/L)	
	Halifax Harbour	Scotian Shelf
Cadmium	0.014 - 0.079	0.025
Copper	0.17 - 0.91	0.25
Iron	1.0 - 6.7	0.50
Manganese	0.44 - 23.5	1.00
Nickel	0.26 - 1.14	0.30
Lead	0.006 - 0.286	0.025
Zinc	0.7 - 70	1.00
Mercury	trace - 0.0025	

Particulate metal concentrations (lead, copper and zinc), in contrast, are significantly higher than typical Scotian Shelf values but similar to those in some Nova Scotia coastal areas (Ferguson's Cove and the LaHave River estuary) (Dalziel *et al.* 1991) (Table 3.8, Figure 3.16). There is no appropriate standard with which to evaluate elevated particulate metal concentrations, but these levels also suggest a significant level of contamination occurring in Halifax Inlet.

Very high levels of particulate manganese seen in the deepest samples in Bedford Basin, however, do not stem from anthropogenic contamination, but result from natural release of dissolved manganese from sediments low in oxygen, and the subsequent precipitation of the metal in the more-oxygenated conditions of near-bottom waters (Dalziel *et al.* 1991). High levels of particulate iron, also found in deep water, appear to be due to iron oxides attached to sediment particles brought into the Basin by surface water inflow, principally the Sackville River. Some metals such as cadmium, however, do not show a striking difference in concentration between Halifax Inlet and Scotian Shelf waters (Figure 3.16). In general, both dissolved and particulate metal concentrations decrease from the inner to the outer harbour (Dalziel *et al.* 1989; 1991).

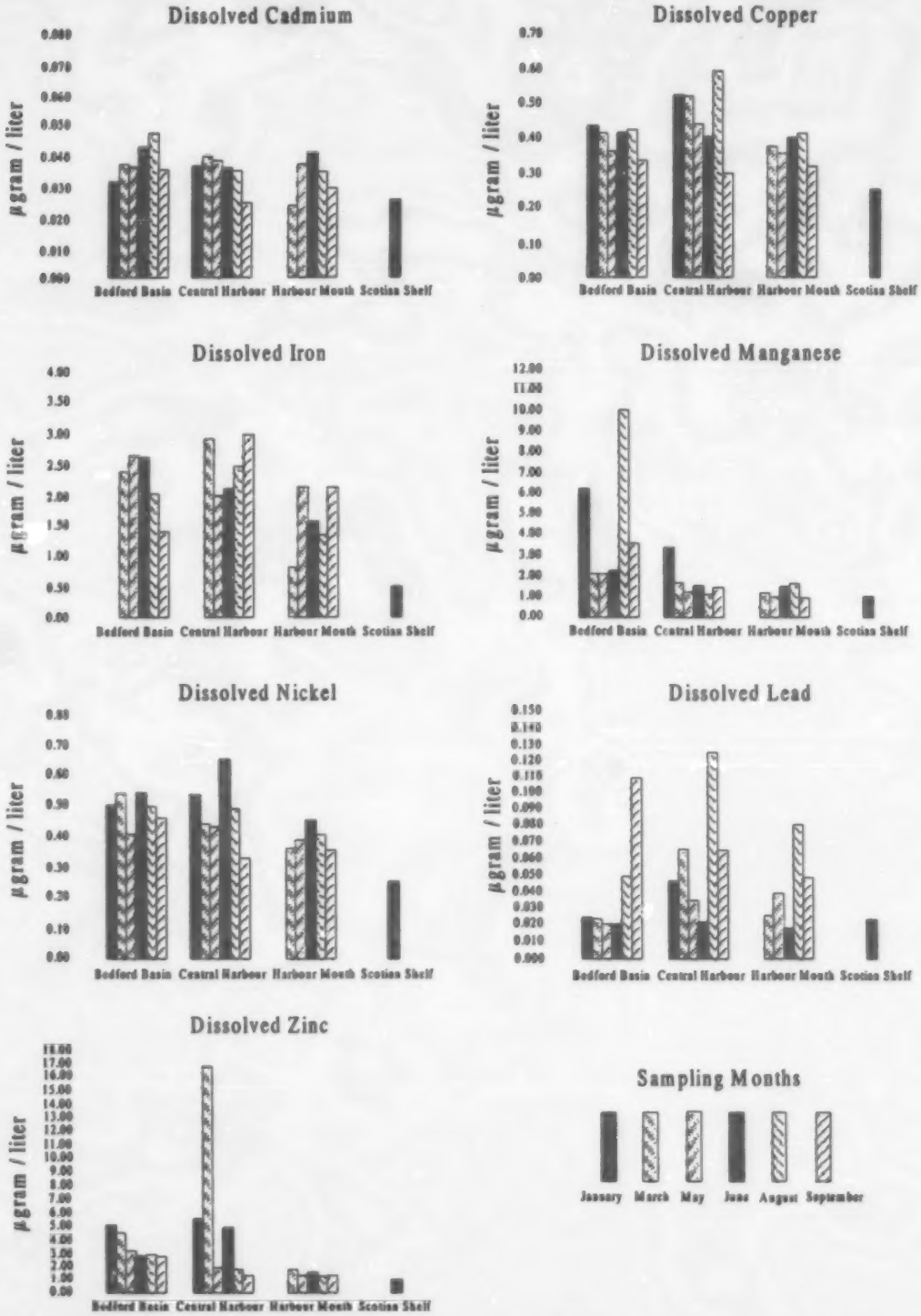


Figure 3.15. Dissolved metal concentrations in the waters of Halifax Inlet, compared with the Scotian Shelf (from Dalziel *et al.* 1991).

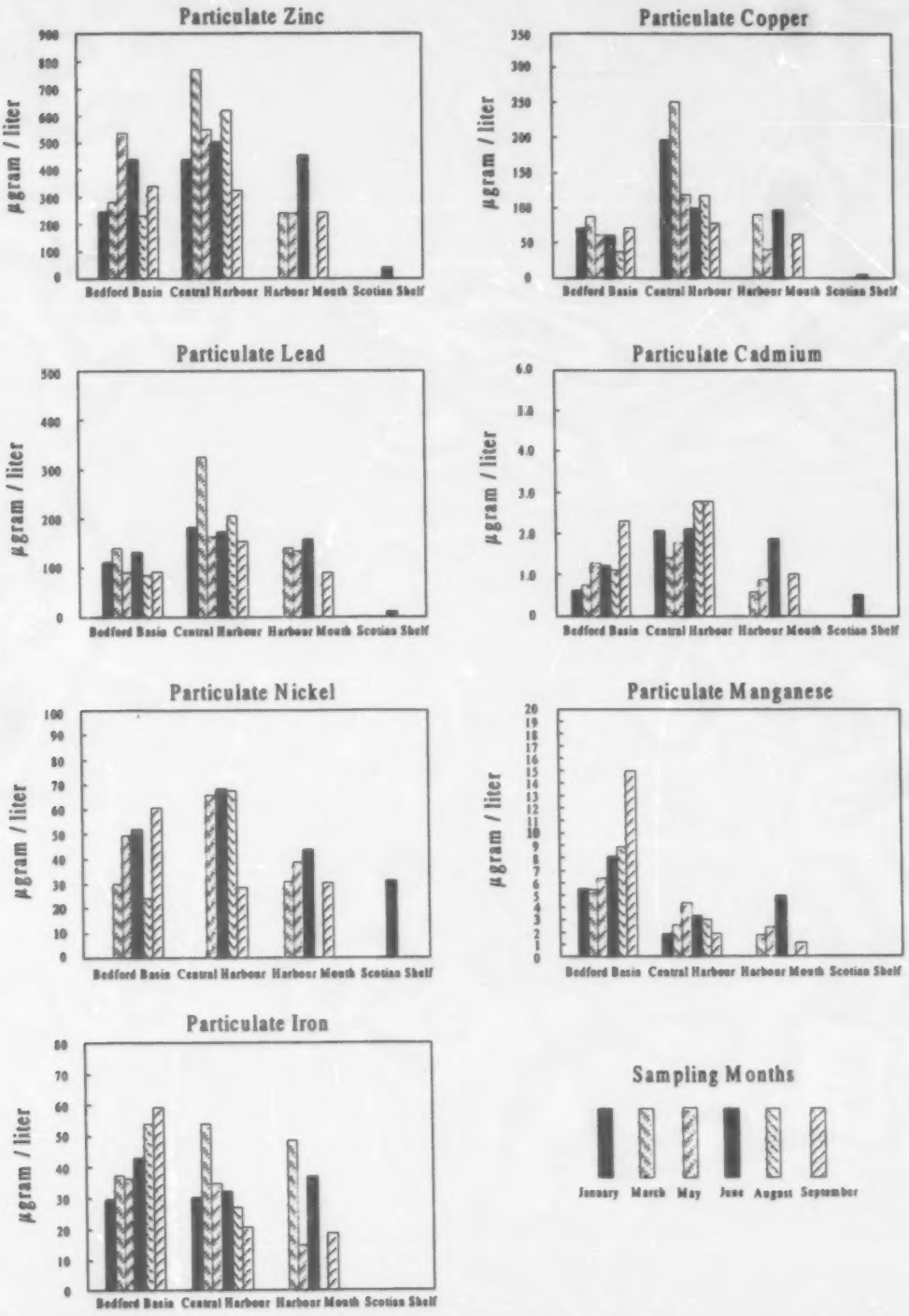


Figure 3.16. Particulate metal concentrations in the waters of Halifax Inlet, compared with the Scotian Shelf (from Dalziel *et al.* 1991).

Table 3.8. Particulate metal concentrations in Halifax Harbour (from Dalziel *et al.* 1991).

	Concentration (ug/g)				
Metal	**Halifax Harbour**	**Bedford Basin [1]**	**Ferguson's Cove (Outer Harbour) [1]**	**La Have Estuary [2]**	**Scotian Shelf**
Aluminum	21,000	26,000	33,000	69,000	–
Cadmium	1.9	1.8	1.8	–	0.5
Copper	106	135	55	89	4
Iron	53,200	24,700	20,600	52,600	–
Lead	164	288	152	200	8
Manganese	9,930	8,080	1,620	698	–
Nickel	46	41	31	–	30
Zinc	422	525	250	199	50

1. Yeats and Dalziel (1987)
2. Cranston *et al.* (1975)

Petroleum hydrocarbon concentrations in Bedford Basin in the late 1970s were elevated over values for open ocean waters and St. Margaret's Bay but were low relative to many waters affected by industrial and urban development (Gordon *et al.* 1978) (Table 3.9). Those authors concluded that all the hydrocarbons found were anthropogenic, and suggested that peak use of fuel oils for heating, transportation and thermal electrical generation in the cities of Halifax and Dartmouth in winter appears to have caused a corresponding pattern in hydrocarbon concentrations in Bedford Basin waters (Gordon *et al.* 1978). No recent measurements of hydrocarbon concentration in Halifax Inlet waters are available.

Table 3.9. Concentration of petroleum hydrocarbons in Bedford Basin (1975-76) and St. Margaret's Bay (1975) (from Gordon *et al.* 1978).

	Hydrocarbon Concentration			
	Bedford Basin		St. Margaret's Bay	
	2 metres	50 metres	2 metres	50 metres
Crude Oil Equivalents (µg/L)	2.5	1.8	0.5 - 0.7	0.2 - 0.7
Total n-alkanes (ng/L)	220	180	52 - 240	206 - 1,100

Sediments

Levels of contaminants in sediments in Halifax Inlet are comparable to those in other major industrialized ports around the world (Hargrave and Buckley 1989; Gearing *et al.* 1991; Buckley and Winters 1992). Nonetheless, comparatively few studies have been carried out profiling contaminant concentrations and distributions in sediments here. For example it was not until the late 1980s that an in-depth study of geochemical properties of sediments in Halifax Inlet was carried out (Buckley and Winters 1992; Buckley *et al.* 1995) (see text boxes, pages 62 and 64). Levels of contaminants of concern, including metals and some organic contaminants, have also been determined periodically for areas of the Inlet requiring dredging and proposed as sites for ocean dumping, although these samples are frequently taken adjacent to wharves and industrial facilities and often show enhanced contaminant concentrations (OceanChem 1985), often of locally-generated substances such as petroleum hydrocarbons and PAHs (e.g. from creosoted timbers) associated with nearby activities. Such measurements in Halifax Inlet have frequently been made for ocean dumping purposes, but with the exception of OceanChem (1985) have not been compiled, and only the latter results are discussed here.

Metals—Average sediment concentrations of copper, lead, mercury and zinc from Halifax Inlet are greater than background levels in eastern Canadian estuarine and coastal sediments by as little as 2 times for mercury and up to 6.4 times for lead (Buckley and Hargrave 1989) (Figure 3.17). Fine-grained and organic-rich sediments, such as occur in Bedford Basin, the central harbour and Northwest Arm, tend to have highest concentrations of metals (Buckley and Winters 1992) (see Figure 3.9 for inlet divisions referred to in the text). Exceedingly high concentrations (including total Cu above 250 μg/g; Zn above 500 μg/g; Pb above 500 μg/g; and Hg above 2 μg/g) occur in sediments near raw sewage outfalls in the central harbour and in the Northwest Arm (Buckley and Winters 1992) (Table 3.10). In one case, an exceedingly high mercury concentration (10.6 μg/g) was found adjacent to a sewage outfall on the Halifax waterfront (see text box, page 64), while excessive metal levels in several isolated samples (particularly lead, in one sample reaching 832 μg/g) have been found adjacent to some industrial facilities, suggested to be due to wastes from ship maintenance, particularly lead-based paint (Buckley and Winters 1992). Levels of mercury above 0.75 μg/g cannot be dumped at sea under Canadian ocean dumping guidelines, and sediment concentrations of lead above 66 μg/g normally require screening prior to ocean disposal because of potential effects to biological organisms. Earlier sampling (see OceanChem 1985) also documented levels of some contaminants above the ocean dumping limits—cadmium at the Sackville River mouth and mercury in Dartmouth Cove (Tables 3.10 & 3.11) (Oceanchem 1985).

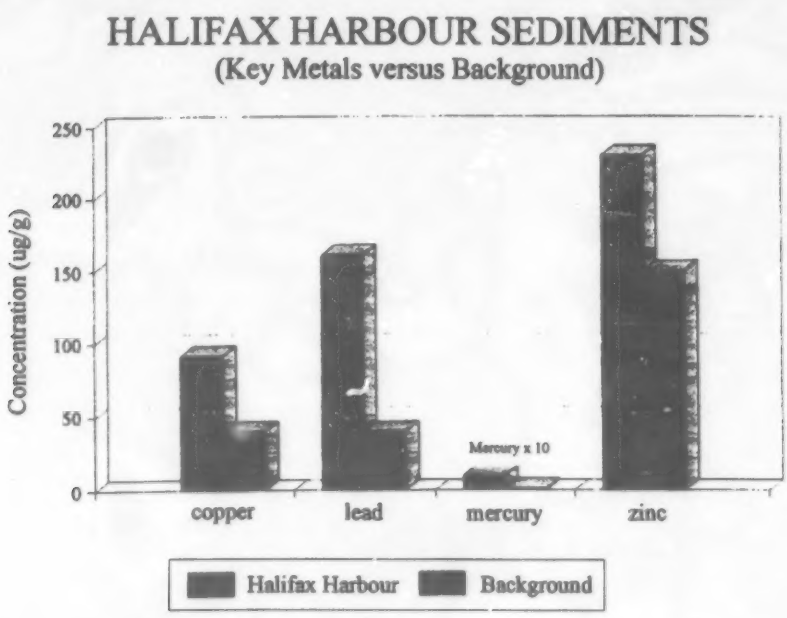


Figure 3.17. Metal content of Halifax Inlet sediments versus background (data from Buckley and Hargrave 1989; background levels from Loring *et al.* 1996).

Table 3.10. Representative contaminant concentrations from surface sediments in Halifax Inlet and Approaches.

	Concentration				
	Halifax Harbour (Grab Samples)[1]	Halifax Harbour (Cores)[2] 1900-present	Tuft's Cove [3]	Central Bedford Basin [4]	Northwest Arm [5]
Metals (ug/g)					
Copper	91	88	323	96	109
Cadmium	85.2	–	1.4	0.8	
Lead	160	206	281	231	231
Manganese	663	–	–	–	
Mercury	0.92	1.6	12.0	1.3	1.25
Zinc	226	249	9,582	273	274
Organics (ug/g)					
PAHs (Total)	–	–	14.4	8.8	20 - 27
Aliphatic Hydrocarbons	–	–	–	–	1,770

1. Buckley and Winters (1992)
2. Buckley et al. (1995)
3 & 4. Tay et al. (1991), average of two stations.
5. Gearing et al. (1991), maximum values.

Table 3.11. Sediment concentrations of contaminants in areas of Halifax Inlet requiring dredging (from OceanChem 1985).

	Concentration		
	Sackville River Mouth	Dartmouth Cove	Eastern Passage
Metals			
Cadmium (ug/g)	< 0.02 - 1.7 (avg 0.6)	1.51 - 1.87 (avg. 1.69)	0.32 - 0.38 (avg. 0.35)
Copper (ug/g)	15 - 19 (avg. 16.6)	151 - 223 (avg. 187)	26.4 - 38.0 (avg. 32.2)
Lead (ug/g)	17 - 37 (avg. 24)	418 - 590 (avg. 504)	26.4 - 35.4 (avg. 30.9)
Mercury (ug/g)	0.05 - 0.07 (avg. 0.05)	1.52 - 2.99 (avg. 2.26)	0.15 - 0.27 (avg. 0.21)
Zinc (ug/g)	41 - 68 (avg. 50.6)	402 - 436 (avg. 419)	75.8 - 107.6 (avg. 91.7)
Chlorinated Organics			
PCBs (Total, ng/g)	40 - 110 (avg. 70)	< 1.7	54 - 92 (avg. 73)
DDTs (Total, ng/g)	< 5	140 - 410 (avg. 275)	31 - 36 (avg. 33)

Organic Contaminants—The principal organic contaminants of Halifax Inlet sediments are petroleum hydrocarbons and PAHs; other contaminants including PCBs, pesticides, and anti-foulants such as tributyltin, though present, have rarely been studied here. Petroleum hydrocarbons are major contaminants, with average levels in sediments the highest found along the Atlantic coast of Nova Scotia (Figure 3.6). These compounds originate principally in fuels and lubricants, and their presence in sediments is usually described in terms of measures of total petroleum hydrocarbon, hydrocarbon equivalents, or content of "oil and grease". In Halifax Inlet, highest concentrations occur in shallow, nearshore waters and areas close to sewage outfalls and industrial, port, and boating facilities. Average levels are highest in the Northwest Arm and on the Halifax/Dartmouth harbourfront, with Northwest Arm averages in 1978 (101.5 μg/g) the highest on the Nova Scotia Atlantic coast for that year (Levy *et al.* 1988; Figure 3.6), approximately four times greater than the Atlantic Canada average of 23 μg/g (Levy *et al.* 1988). Levels in Northwest Arm ranged from 11 to 195 μg/g in 1978 (Levy *et al.* 1988) to a high of 1,770 μg/g in 1989 (Gearing *et al.* 1991); on the Halifax/Dartmouth waterfront from 1 to 377 μg/g; and in Bedford Basin, from 1.5 to 126 μg/g (Levy *et al.* 1988).

Recent levels of petroleum hydrocarbons are significantly above levels found in sediments deposited in Northwest Arm before 1900 (which averaged 18 μg/g), and above levels of 1 to 5 μg/g found on the Scotian Shelf (Gearing *et al.* 1991). An oil and grease content of 10 μg/g is normally considered an unacceptable level for ocean dumping and levels of 500 μg/g or more are considered to cause ecological damage (Olsen *et al.* 1982 from Gearing *et al.* 1991).

Polycyclic aromatic hydrocarbons (PAHs) in Halifax Inlet sediments occur at concentrations which are among the highest in the world, stemming both from heavy industrial activity and the

burning of fossil fuels in the Halifax urban area. Some of the highest concentrations occur in surface sediments in Northwest Arm, where PAH concentrations reach 20 to 27 μg/g dry weight in mid-portions (Gearing *et al.* 1991) and 5.37 μg/g near the mouth (S. MacKnight, pers. comm, in Gearing *et al.* 1991). From their composition, most PAHs in sediments have arisen as byproducts of combustion (Gearing *et al.* 1991). Other parts of Halifax Inlet show concentrations of PAHs in sediments from less than 1.0 to 42.1 μg/g, but up 2,996 μg/g (a level comparable to that in contaminated Sydney Harbour sediments, see Section 3.4) adjacent to a thermal-fired generating station (Tay *et al.* 1991; MacKnight pers. comm, from Gearing *et al.* 1991; Tay *et al.* 1992; O'Neill and Kieley 1992) (Table 3.10). Overall, levels of PAHs in Halifax Inlet are considerably higher than reported for many other industrialized or contaminated coastal areas such as San Francisco Bay, the New York Bight dumpsite, Tokyo Bay and Puget Sound near Seattle (Gearing *et al.* 1991) (Table 3.12). Levels thus frequently, and sometimes significantly, exceed the ocean dumping guideline for PAHs in sediments, and are likely to be highly toxic to marine organisms (Environment Canada 1995; CCME 1999).

Table 3.12. Comparison of PAH concentrations (ng/g) in sediments (from Gearing *et al.* 1991).

Location	Reference [a]	Combustion products [b]	Pyrene	Benzo[a]pyrene
Sydney Harbour, NS	12	280,000	33,000	28,000
Baltimore Harbour	1	169,000	57,600	1,050
Charles River, MA	2	87,000	13,000	–
Halifax Harbour, 5-10cm	**This Study**	**26,700**	**5,500**	**2,600**
San Francisco Bay	3	12,000	–	–
Severn Estuary, UK	4	8,000	1,400	470
LaPlate Harbour, Argentina	5	6,000	1,400	200
New York Bight	2	5,800	1,300	–
Upper Penobscot Bay	6	6,000	450	490
Tokyo Bay	7	–	600	500
Lake Michigan	8	5,000	600	300
Gdask Harbour, Poland	9	3,000	46	–
Puget Sound, Seattle	10	1,300	88	–
Gulf of Maine	2	540	100	–
Halifax Harbour, 45-50cm	**This Study**	**300**	**nd**	**15**
Pacific Shelf	11	290	53	25
Atlantic Abyssal Plain	2	55	4	nd

[a] References: 1, Fostor and Wright (1988); 2, LaFlamme and Hites (1978); 3, Chapman et al. (1978b); 4, Thompson and Eglinton (1978); 5, Colombo et al. 1989); 6, Johnson et al. (1985); 7, Ohta et al. (1983); 8, Helfrich and Armstrong (1986); 9, Lamparczyk et al. (1988); 10, Barrick and Prahl (1987); 11, Prahl and Carpenter (1983); 12, Kieley et al. (1988).
[b] Sum of nine products used in this study.

Elevated levels of polychlorinated biphenyls (PCBs) were found in sediments in the 1970s and early 1980s in some nearshore areas of Halifax Inlet, occasionally approaching or exceeding the ocean dumping limit of 100 ng/g. Ranges were comparable in the mid 1970s and early 1980s near wharves at Eastern Passage on the eastern shore of Halifax Inlet near the mouth (12 - 81 ng/g, Leonard 1977; 54 - 92 ng/g, OceanChem 1985), but levels up to 800 ng/g had earlier been found near refineries and wharves in the area (Travers and Wilson 1977). In other parts of Halifax Inlet in the early 1980s, levels ranged from less than 2 ng/g in Dartmouth Cove to 40 - 110 ng/g at the mouth of the Sackville River (OceanChem 1985) (Table 3.11). Most levels are much greater than PCB concentrations in uncontaminated sediments in Chezzetcook Inlet, 20 km east of Halifax, which were below the detection limit of 5 ng/g (Travers and Wilson 1977) (see also Section 1.3). No recent assessments of concentrations of PCBs in sediments have been undertaken, and thus neither current levels, nor temporal trends, can be determined.

Levels of total DDT in sediments have only occasionally been reported for Halifax Inlet. At Eastern Passage in the mid-1970s and early 1980s, levels ranged from low (less than 1 ng/g) to significantly elevated (31 - 36 ng/g) (Leonard 1977; OceanChem 1985). In the early 1980s, sediments at the Sackville River mouth had low levels of DDT, while concentrations above the ocean dumping guideline for pesticides of 100 ng/g were found in Dartmouth Cove (OceanChem 1985, Table 3.11). These levels are much higher than background levels of less than 1 ng/g dry weight measured near wharves on the Eastern Shore (Leonard 1977). Maximum levels were above the current interim Canadian sediment quality guideline for marine life of 3.9 ng/g for total DDT (Environment Canada 1995). No recent information is available to determine if DDT concentrations in these areas continue to be a concern.

In the late 1970s, recognition of the toxicity to marine organisms of the anti-foulant chemical tributyltin, used widely since the 1960s in ship paints and fishing-gear treatments, led to several studies of its distribution in harbour sediments in the Atlantic provinces. Tributyltin in Halifax Inlet sediments has ranged from below the limit of detection (Maguire *et al.* 1986) to from 2.7 to 87 μg/g in sediments under the slipway of a Dartmouth ship repair facility (Hennigar and Garron 1986). More recent sampling (1988 & 1994) in areas having heavy vessel traffic and at ship repair facilities in Halifax Harbour gave butyltin (total of mono, di- and tributyltin) concentrations in sediments ranging from 0.024 μg/g to 6.5 μg/g dry weight (W. Ernst, Environment Canada, Personal Communication). These levels are likely to be toxic to sediment-dwelling organisms, but no guidelines to assess levels of concern are available.

Biota

Lobster—Concentrations of major trace metals (cadmium, copper, mercury, lead, and zinc) in digestive glands of lobster (*Homarus americanus*) in Halifax Inlet are generally low and below levels hazardous for human consumption, although in some cases they show local variability which may be linked to environmental contamination (Uthe *et al.* 1989) (Table 3.13). Compared to other areas of Atlantic Canada, levels of copper, mercury, and lead in Halifax Inlet lobster are slightly higher; zinc is within reported ranges; while cadmium concentrations are significantly lower (Uthe *et al.* 1989) (Tables 1.5 & 3.13) (Uthe *et al.* 1989). Silver content of the digestive gland of lobster fished in the vicinity Halifax has also been found to be slightly elevated (2.22

µg/g, range 0.71 - 5.38) compared with lobster in other areas in Atlantic Canada (Chou and Uthe 1978). No comparative data on levels of concern for this metal are available.

Table 3.13. Concentrations of trace metals, PAHs and PCBs in the digestive glands of lobster from Halifax Harbour, January and September 1989 (from Uthe *et al.* 1989 & Prouse 1991).

	Concentration (µg/g wet weight)					PAH (Total, ng/g)	PCB (Total, µg/g)
Location	Cadmium	Copper	Mercury	Lead	Zinc		
January 1989 [1]							
Dartmouth Cove	34	1990	24	164	250	2.34	56
Bedford Basin	66	697	11	244	245	2.77	14
Harbour Mouth	65	356	13	175	208	1.19	12
September 1989 [2]							
Dartmouth Cove	–	233.8 - 239.7	0.13 - 0.19	–	–	–	–
Bedford Basin (Birch Cove)	–	99.5 - 139.0	0.10 - 0.13	–	–	–	–
Northwest Arm	–	15.4 - 31.2	0.11 - 0.13	–	–	–	–
Outer Harbour – Portuguese Shoal	–	45.1 - 84.1	9	–	–	–	–
Outer Harbour – Thrumcap Shoal	–	74.0 - 95.3	9	–	–	–	–
Background							
Halifax Area [3]	4.64 - 15.1 (avg. 8.59)	25.4 - 426 (avg. 120)	–	–	20.6 - 43.2 (avg. 27.7)	–	–

1. Uthe et al. (1989)
2. Prouse (1991)
3. Chou and Uthe (1978)

Concentrations of PAHs in digestive glands of lobster from Halifax Inlet appear to be significantly higher than in lobster from 'clean' areas of the Atlantic Coast (Section 1.3) but below levels likely to result in unacceptable levels in the tail muscle (which is the generally-consumed part of the lobster) (Uthe *et al.* 1989). Levels of 1 ng/g wet weight benzo(*a*)pyrene in lobster meat is considered unacceptable for human consumption (Uthe 1979, from Eaton *et al.* 1986). Levels of total PAH in the digestive glands of Halifax Harbour lobster are significantly below those found in parts of Sydney Harbour where fishing is still permitted (see Section 3.4.5), where the corresponding level of benzo(*a*)pyrene in the tail muscle meets acceptable food quality standards. Levels of PAHs in lobster digestive gland are highest in Bedford Basin and Dartmouth Cove and lowest at the Harbour mouth (Table 3.13) (Uthe *et al.* 1989), where they are comparable to levels of from 54 to 1,517 ng/g found in catch in the area in 1979 (Scarratt 1980).

PCB concentrations in digestive glands of lobster sampled from Halifax Inlet also appear to be elevated, and in at least one case (Dartmouth Cove) exceeded the Health and Welfare Canada guideline for PCB concentration in fish products (2.0 μg/g) (Table 3.13) (Uthe *et al.* 1989). Levels in the meat are typically much below those in the digestive gland, and all samples would be acceptable for human consumption. Of other chlorinated organic compounds of potential concern, Uthe *et al.* (1989) found no hexachlorobenzene in lobster digestive gland although low levels (below limits of quantification) of p,p'-DDE were found.

Levels of petroleum hydrocarbons in lobster in Halifax Inlet are not significant and do not presently pose a concern, and a successful commercial fishery takes place there (Prouse 1994). Nonetheless, in the late 1970s, levels of hydrocarbons of 1,630 ng/g wet weight were measured in the digestive gland of one lobster held at the Fisheries and Oceans Canada Halifax Research Laboratory (Scarratt 1980), exceeding levels in lobsters from the Canso/Chedabucto Bay area, which were more likely to have been impacted by oiling from a tanker spill (*Kurdistan*, see Section 3.5.5), and suggesting that the Harbour was contaminated with hydrocarbons. This is the only reported measurement and clearly the absence of other information represents a data gap.

Mussels—Concentrations of several metals measured in Halifax Inlet mussels (*Mytilus edulis*) are elevated over nearby areas as well as compared with other coastal areas of the world (Ward 1990; Zenon Environmental Inc, 1989MS). In the late 1980s, of the metals copper, lead and zinc, only zinc was higher in mussels in Halifax Inlet than just outside the harbour, with the highest concentration occurring in Wright's Cove on the northeast side of Bedford Basin (Ward 1990) (Figure 3.18). Levels of copper (13.7 to 154.3 μg/g dry weight), lead (3.1 to 12.1 μg/g), and zinc (108.8 to 552.0 μg/g) (Ward 1990), however, all were significantly above average levels for U.S. Mussel Watch sites (Ward 1990; O'Connor 1992) (Table 1.4), while the highest lead level was above the acceptable limit for human consumption of marine shellfish products (CSSP 1992); and highest copper levels were above the only food guideline available (the 70 μg/g guideline for mollusc exports to Australia, Fisheries and Oceans Canada Products Inspection Manual); although the highest zinc was below the guideline for oyster export.

Mussels from Dartmouth Cove and the Bedford area of Halifax Harbour in 1989 (Table 3.14) (Zenon Environmental Inc. 1989 MS) showed cadmium levels elevated above those reported for an unspecified location in the Halifax area (0.2 μg/g dry weight) (Cossa 1988), while compared to mussels from a 'pristine' coastal site (Beaver Harbour, Table 3.5), only lead and zinc were significantly elevated (from 2 to 8 times). Allowing for wet weight/dry weight differences, chromium, lead and zinc in Halifax Inlet mussels are elevated and mercury reduced over averages for U.S. mussel watch sites (O'Connor 1992) (Table 1.4). Halifax Inlet mussels also contained phthalate acid esters (plasticizer chemicals), methylene chloride, and the carboxylic acid pesticide picloram, but key PAHs were below 100 ng/g or not present (Table 3.14).

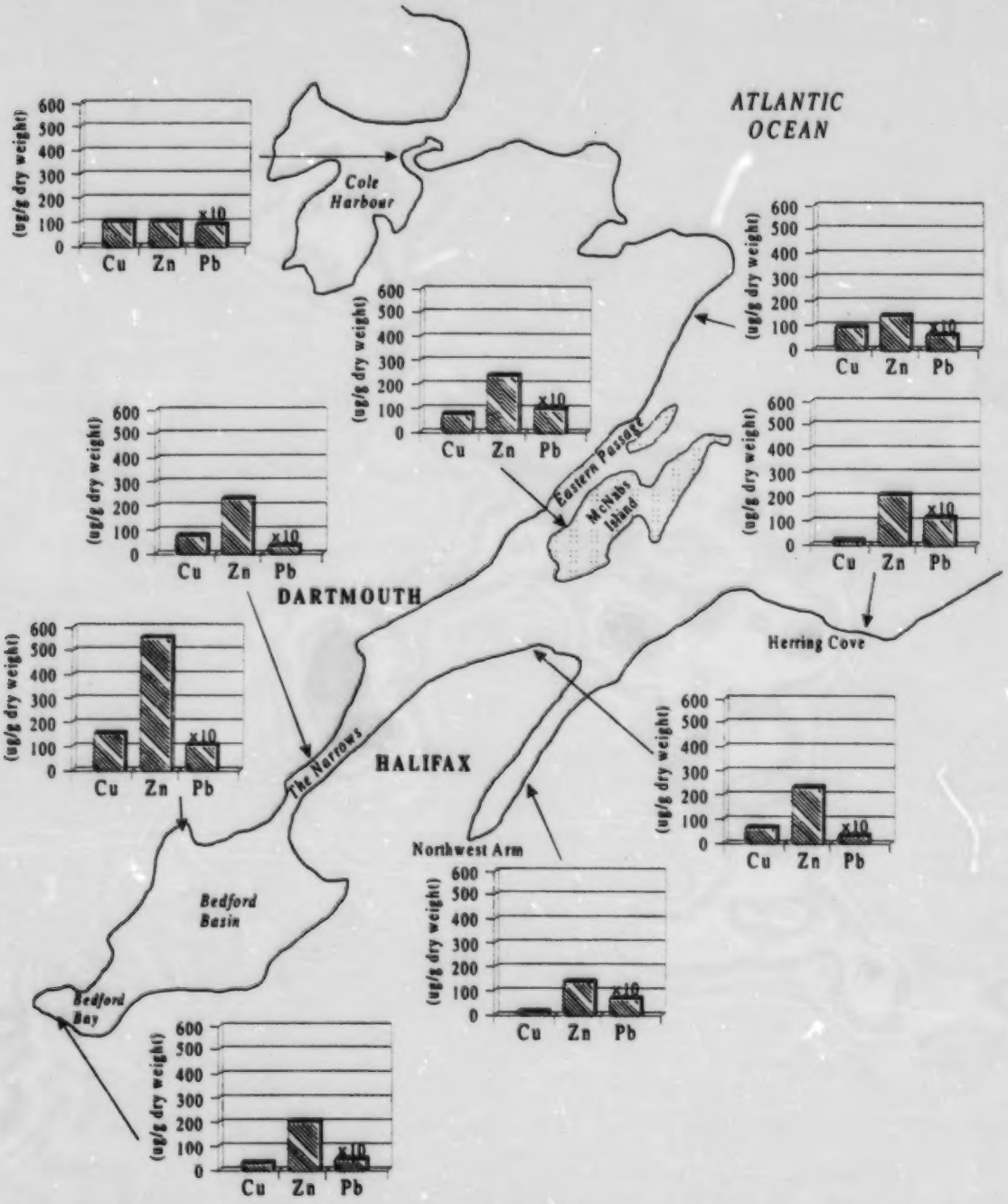


Figure 3.18. Concentrations of major metals in mussels *Mytilus edulis* from locations in Halifax Inlet and adjacent areas (data from Ward 1990).

Table 3.14. Concentrations of contaminants found in mussels from Halifax Harbour in a survey of metals, volatile and semi-volatile organics, PAHs, chlorinated organics, pesticides and aromatic amines carried out by Environment Canada. Only contaminants which were detected are presented (Zenon Environmental Inc. 1989MS; G. Julien, Environment Canada, Personal Communication).

Contaminant	Concentration (µg/g wet weight)	
	Dartmouth Cove	Bedford Basin
Metals		
Arsenic	1.1 µg/g	0.83 µg/g
Cadmium	0.44 µg/g	0.17 µg/g
Chromium	0.57 µg/g	0.31 µg/g
Copper	1.3 µg/g	1.9 µg/g
Iron	57 µg/g	32.0 µg/g
Lead	2.4 µg/g	3.9 µg/g
Mercury	0.039 µg/g	0.11 µg/g
Silver	less than 0.3 µg/g	less than 0.3 µg/g
Zinc	41 µg/g	24 µg/g
Organics		
bis(2-ethylhexyl) phthalate [1]	0.45 µg/g	0.58 µg/g
di-n-octyl phthalate [1]	0.15 µg/g	0.44 µg/g
methylene chloride	not detected	0.11 µg/g
picloram [2]	less than 0.03 µg/g	less than 0.06 µg/g
Selected PAHs benzo(a)anthracene benzo(a)pyrene fluoranthene pyrene triphenylene	none detected (detection limit, < 0.1 µg/g)	none detected (detection limit, < 0.1 µg/g)

1. plasticizer;
2. carboxylic acid pesticide.

Fish—No measurements of contaminants in fish have been made for Halifax Inlet although occasionally fish from Halifax-area coastal waters have been used to determine contaminant load. In the early 1970s, mercury concentrations in fish were relatively low in the waters off Halifax Harbour (Freeman *et al.* 1974) (Table 3.15). Cod sampled in the early 1980s in inshore areas off Terence Bay, near the mouth of Halifax Harbour, however, had levels of PCBs (2 - 9 µg/g) elevated above background, though similar to those found in cod from other coastal areas (Freeman *et al.* 1982, 1983) and reflecting a broader contamination problem. Levels in cod livers from offshore areas of the North Atlantic, by comparison were lower, ranging from 0.4 to 2 µg/g

in the late 1970s (ICES 1977a from Zitko 1981). A level of PCBs of 2 μg/g in fish tissue is considered unacceptable for human consumption. A later study (1980) found various chlorinated organic compounds (PCBs, organochlorine pesticides and chlorobenzenes) in cod livers from waters in the Halifax area at levels similar to those found in the earlier studies, although a decline in PCBs and DDT concentrations was observed between 1972 and 1975 (Freeman *et al.* (1984)) (Table 3.16).

Table 3.15. Concentrations of mercury in fish caught off Halifax Inlet and nearby areas (from Freeman *et al.* 1974).

Species	Concentration (ug/g wet weight)
ATLANTIC OCEAN OFF HALIFAX	
Redfish *(Sebastes marinus)*	0.11 - 0.16
Atlantic cod *(Gadus morhua)*	0.04 - 0.34
Gaspereau *(Alosa pseudoharengus)*	0.05 - 0.29
Shad *(Alosa sapidissima)*	0.07 - 0.11
American Plaice *(Hippoglossoides platessoides)*	0.12 - 0.15
Winter Flounder *(Pseudopleuronectes americanus)*	0.11 - 0.20
Sea Raven *(Hemitripterus americanus)*	0.15 - 0.45
Thorny Skate *(Raja radiata)*	0.12 - 0.41
ST. MARGARET'S BAY	
Atlantic Mackerel *(Scomber scombrus)*	< 0.005 - 0.16

Table 3.16. Polychlorinated biphenyls, organochlorine pesticides and chlorobenzenes in cod livers caught off Halifax (from Freeman *et al.* 1984).

Compound	Concentration and Range (ug/g wet weight)
PCB	1.71 (0.24 - 4.33)
p,p'-DDE	0.28 (0.01 - 0.84)
p,p'-DDD	0.10 (trace - 0.84)
p,p'-DDT	0.15 (n.d. - 0.58)
Total DDT	0.53
α-HCH	0.06 (trace - 0.10)
μ-HCH	(n.d - trace)
heptachlor	0.02 (n.d. - 0.04)
heptachlor epoxide	0.15 (n.d. - 2.16)
dieldrin	0.06 (n.d. - 0.71)
hexachlorobenzene	0.02 (trace - 0.05)
n.d. = not detectable	

3.3.6 Summary and Conclusions

Halifax Inlet is one of the most industrialized inlets on the Atlantic coast of Nova Scotia, and is the location of one of its largest population centres. As a consequence of the widespread use of the waters as a depository for industrial wastes and domestic sewage, the Inlet shows significant anthropogenic contamination. In particular, surface sediments contain concentrations of metals and PAHs, comparable to the most significant cases of contamination in harbours around the world, while levels of organochlorine contaminants such as PCBs are also significantly elevated over background levels. Nonetheless, the most severe contamination is often localized spatially (e.g. near sewer outfalls and industrial facilities) or in different environmental compartments (i.e. higher levels of metals in sediments versus more moderate levels in dissolved and particulate form in water) so that impacts on the environment, biota, and human use of the harbour are only moderate. Proposed treatment of domestic sewage, and all-around better controls on contamination of the harbour by various industries, should greatly reduce the load of various contaminants entering Halifax Inlet, and should lead to improved conditions, although sediments will continue to have elevated levels of contaminants in sediments for the longterm.

3.4 SYDNEY HARBOUR

Sydney Harbour on the northeast coast of Cape Breton Island has developed as an industrial, transportation and population centre, probably second only to Halifax/Dartmouth on the Atlantic Coast in overall development and level of activity. In common with other industrial ports, the Harbour has been the depository of industrial and anthropogenic contamination, and its physical characteristics—a shallow, estuarine system in a drowned river valley where fine sediments, including those containing elevated levels of contaminants, accumulate— has added contamination problems. Contamination of Sydney Harbour has been dominated, however, by a case of massive industrial contamination—the release into Sydney Harbour of high concentrations of a range of hazardous substances, principally polycyclic aromatic hydrocarbons (PAHs) but including other organic contaminants as well as metals—from a steel smelter and coke ovens on its shores. Operation of the blast furnaces until the early 1980s (they have since been shut down) also resulted in toxic air emissions that became a health concern through suspected elevated cancer risk for residents, while the PAH contamination of harbour waters has led to closure of the lobster fishery in parts of the inlet. The clean-up of the Sydney Tar Ponds and Muggah Creek into which much of the contaminants from the smelter and associated facilities flowed and accumulated (acknowledged to be the most hazardous toxic waste site in Canada), has been one of the most expensive, long-term, and controversial environmental undertakings in Canadian history—and one that is far from being over.

3.4.1 Oceanography

Sydney Harbour is a shallow (maximum depth 19 m) Y-shaped inlet, 21 km long and 3 km wide at the mouth, situated on the northeastern coast of Cape Breton Island (Vandermeulen 1989; Gregory *et al.* 1993). The inlet is a 'drowned' river valley, typical of the indented coast along the largely sedimentary shores of the coal-rich Sydney Basin—an easily-eroded geological formation which has been flooded by rising sea level (Figures 3.19 & 3.20).

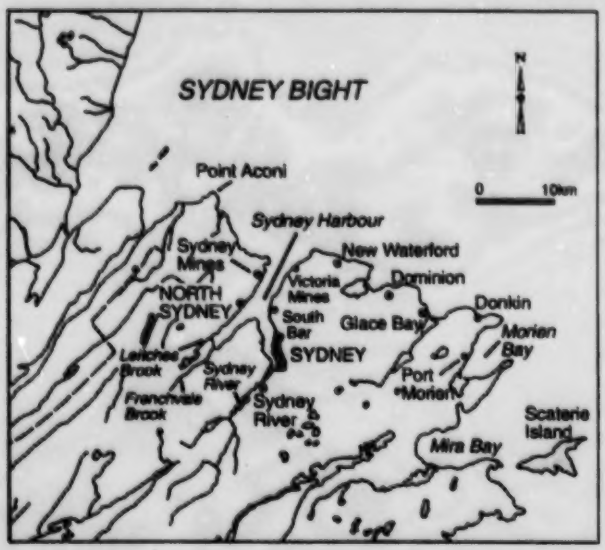


Figure 3.19. Sydney Harbour and adjacent areas.

The southeastern arm of the harbour (South Arm) forms a basin—bounded at its mouth by a shallow bar at a depth of 13 m, and 17-19 m deep in the centre (OceanChem 1984) (Figure 3.20)—while the Northwest Arm shallows gradually to its head. Sydney Harbour is estuarine, receiving freshwater inflow from Sydney River (average annual flow of 6.1 cubic metres per second) which enters at the head of South Arm, as well as from a number of smaller watercourses, the largest of which are Muggah Creek (which enters on the eastern shore of South Arm), and Leitches and Frenchvale Brooks (at the head of Northwest Arm). As a

consequence of Sydney River flow, South Arm has a significant two-layer estuarine circulation (surface, low-salinity water, flows toward the sea while the more-saline bottom water flows from the sea towards the head of the Arm). Waters in the Outer Harbour and Northwest Arm, in contrast, are well-mixed horizontally and vertically.

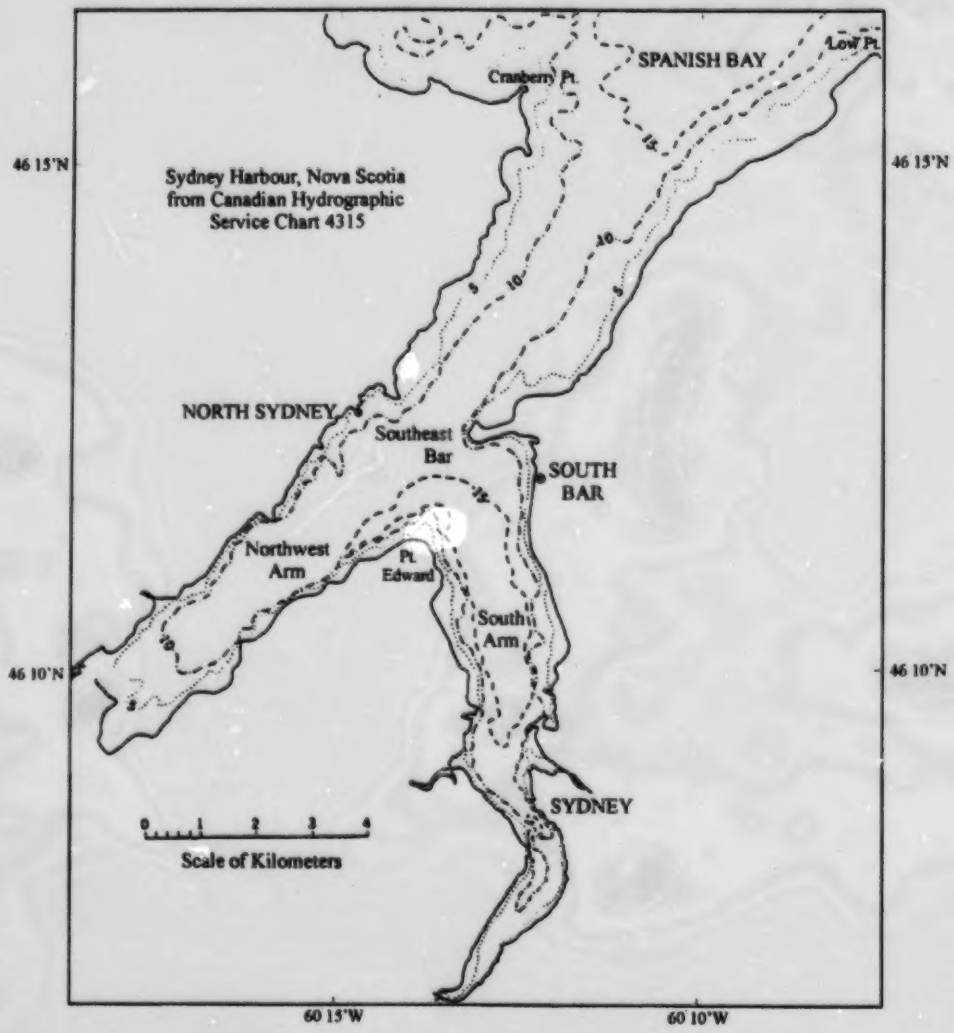


Figure 3.20. Bathymetry of Sydney Harbour (from Vandermeulen 1989).

The inlet as a whole has a flushing time of 5.8 days and mean and peak tidal currents of 3 cm/sec and 5 cm/sec respectively, similar to that of South Arm, while flushing time for Northwest Arm is 4.3 days (Gregory *et al.* 1993). Apart from estuarine circulation, water movements in the Harbour are normally dominated by tidal currents and occasionally by wind during strong wind events (P. Lane and Associates 1988). Tides are semi-diurnal (twice a day) with a mean range of 0.9 m and large tides of 1.4 metres (Owens and Bowen 1977; Gregory *et al.* 1993). Dissolved oxygen becomes depleted in near-bottom waters of South Arm in summer (occasionally reaching

levels below 4 mg/L) and sediments are frequently devoid of oxygen (anoxic), but normal levels above 10 mg/L in bottom waters occur in winter (P. Lane and Associates 1988). The harbour freezes in winter, and in spring is frequently choked with ice which may persist until late April (P. Lane and Associates 1988).

Sediments in shallow subtidal coastal areas of South and Northwest Arms of Sydney Harbour are relatively coarse, having significant sand and gravel components, while sediments in central deeper areas consist principally of silts and clays elevated in organic content (up to 7% organic carbon) (OceanChem 1984; Packman *et al.* MS). The basin in South Arm enhances deposition of particulate material there, but inputs of domestic sewage and industrial contaminants from the City of Sydney are major contributors to elevated organic concentrations in South Arm sediments (OceanChem 1984). In the outer harbour, sediments are coarser, ranging from silty sand to sandy gravel (Packman *et al.* MS)

3.4.2 Biology

Sydney Harbour supports biological communities comparable to those of other coastal areas on the Atlantic Coast of Nova Scotia (See Table 3.3, Section 3.1.3). No assessments of primary productivity and phytoplankton have been carried out, although zooplankton and benthic communities appear from occasional samples, to be representative of Nova Scotia Atlantic coastal species (P. Lane and Associates 1988, 1989; Wendland 1979; Matheson *et al.* 1983). Plankton communities can be expected to reflect more closely waters originating in the Gulf of St. Lawrence (found in offshore waters in the area), than waters elsewhere along the Atlantic coast. Even in heavily polluted portions of South Arm, a range of seabed species may be found, including polychaetes (predominant), nemerteans and anemones (both burrowing and sessile) (Table 3.17). A definite reduction in diversity and abundance of organisms occurs under extreme levels of organic, PAH and metal contamination found at the mouth of Muggah Creek (P. Lane and Associates 1988; Wendland (1979); Matheson *et al.* 1983).

Table 3.17. Benthic invertebrates occurring in Sydney Harbour. Harbour divisions are shown in Figure 3.22 (from P. Lane and Associates (1989) and Wendland (1979)).

Species	Inner South Arm (Sydney River Estuary)	Central South Arm	Muggah Creek	Outer South Arm	Northwest Arm	Outer Harbour
Gastropods	*Littorina* sp	Whelks	Whelks	*Littorina* sp	*Littorina* sp	*Littorina* sp
Bivalves	*Cerastoderma pinnulatum* *Mytilus edulis* *Placopecten magellanicus* *Yoldia limatula*	*Cerastoderma pinnulatum* *Mytilus edulis* *Placopecten magellanicus* *Yoldia limatula*	*Yoldia limatula*	*Modiolus modiolus* [1] *Mytilus edulis* *Placopecten magellanicus*	*Cerastoderma pinnulatum* *Mercenaria mercenaria* [1] *Mytilus edulis* *Placopecten magellanicus* *Yoldia limatula*	*Cerastoderma pinnulatum* *Ensis directus* *Mytilus edulis*
Polychaetes	*Capitella capitata* *Haploscoloplos robustus* *Mysicola infundibulum* *Nephys* sp. *Ninoe nigripes* *Pectinaria gouldii* *Polydora* sp	*Haploscoloplos robustus* *Hydroides dianthus* *Mysicola infundibulum* *Naineris quadricuspis* *Nephys* sp *Nereis diversicolor* *Nereis virens* *Pectinaria gouldii* *Polycirrus* sp	*Nephys* sp *Nereis virens* *Pectinaria gouldii*	*Haploscoloplos robustus* *Mysicola infundibulum* *Nephys* sp *Pectinaria gouldii*	*Capitella capitata* *Haploscoloplos robustus* *Mysicola infundibulum* *Naineris quadricuspida* *Nephys* sp *Nereis virens* *Pectinaria gouldii* *Polycirrus* sp	*Aricidea suecica* *Capitella capitata* *Haploscoloplos robustus* *Hydroides dianthus* *Lumbrineris fragilis* *Mysicola infundibulum* *Naineris quadricuspida* *Nephys* sp *Nereis virens* *Ninoe nigripes* *Pectinaria gouldii* *Polycirrus* sp *Polydora ligni*
Crustacea — Decapoda				*Cancer irroratus* [1] *Crangon septemspinosa* [1]	*Cancer irroratus* [1] *Pagurus* sp [1]	*Pagurus acadianus* *Sclerocrangon boreas*
Amphipoda						*Gammarus mucronatus* *Gammarus oceanicus*
Isopoda						*Chiridotea* sp *Edotea triloba*
Cumacea						*Lamprops quadriplicata*
Echinoderms				*Asterias forbesi* [1]	*Asterias forbesi* [1] *Henricia* sp [1]	*Asterias forbesi* [1] *Strongylocentrotus*
Cnideria	*Edwardsia elegans* *Nematostella vectensis*	*Cerianthus borealis* *Edwardsia elegans* *Nematostella vectensis*	NOT PRESENT	*Nematostella vectensis*	*Edwardsia elegans*	*Edwardsia elegans*
Nemertean Worms	*Micrura leidyi*	*Lineus arenicola*	NOT PRESENT	*Lineus arenicola*	*Lineus arenicola*	*Lineus arenicola* *Lineus ruber*

1. Packman *et al.* unpublished MS

3.4.3 Fisheries

Sydney Harbour supports a range of fish and shellfish species which are representative of those typically occurring in Nova Scotia coastal waters (Vandermeulen 1989; Hildebrand 1982) (See Table 3.3, Section 3.1.3). None of the species, with the exception of lobster, are fished commercially but some recreational fishing for marine species is carried out (Hildebrand 1982). Although the lobster fishery traditionally extended to the international piers in South Arm and to the mouth of Northwest Arm, the South Arm has been closed to lobster fishing since the early 1980s due to PAH contamination in lobster tissues (Prouse 1994; Vandermeulen 1989) (see Section 3.4.5). Sydney River, and Leitches and Frenchvale Brooks which enter the head of the Northwest Arm, nonetheless have important recreational salmon fisheries (Hildebrand 1982).

3.4.4 Anthropogenic Sources of Chemicals

Sydney Harbour has been historically the receiving water for a mix of wastes from various point sources centred on the city of Sydney, and towns of Sydney Mines and North Sydney (populations of 26,060, 7,555 and 7,260 (1991 census) respectively) (Figure 3.19). Various major industries and commercial activities impinge on the harbour, including: shipping (coal, iron ore and steel as well as petroleum and petroleum products); marine transport (e.g. wharves,

container port, ferry terminal); ship repair; fish processing; coal mining and processing facilities; and a major steel mill (Hildebrand 1982; Oceanchem 1984; Vandermeulen 1989). Domestic pollution consists primarily of untreated sewage from the City of Sydney on South Arm and Sydney Mines and North Sydney in outer areas of the Harbour.

The steel mill and associated facilities situated on South Arm have been a major source of contaminants to the Harbour (Figure 3.21). Effluents from the mill have been shown to contain ammonia, iron, phenols, cyanide, and phosphate, while the coking operation at the site (the coke ovens no longer operate, the first having been shut down in November 1981 and the second in November 1983) discharged effluents having a high chemical and biological oxygen demand, suspended and dissolved solids, and containing a wide range of contaminants, including: ammonia, phenols, cyanide, thiocyanate, sulphide, oil and grease, benzene, chloroform, methylene chloride, and toluene, as well as PAHs and metals (Hildebrand 1982; Vandermeulen 1989). Although the coking operation has ceased, PAHs and various coal tar derivatives, as well as PCBs (likely occurring in sediments as the result of uncontrolled dumping by the general populace and local industries into Muggah Creek, the watershed into which the steel plant discharged effluent) continue to escape and enter the Harbour (Vandermeulen 1989; P. Lane and Associates 1988-1990). The steel plant in past was also a major source of atmospheric emissions (total suspended particulates, sulphur dioxide, and PAHs) (Eaton *et al.* 1994).

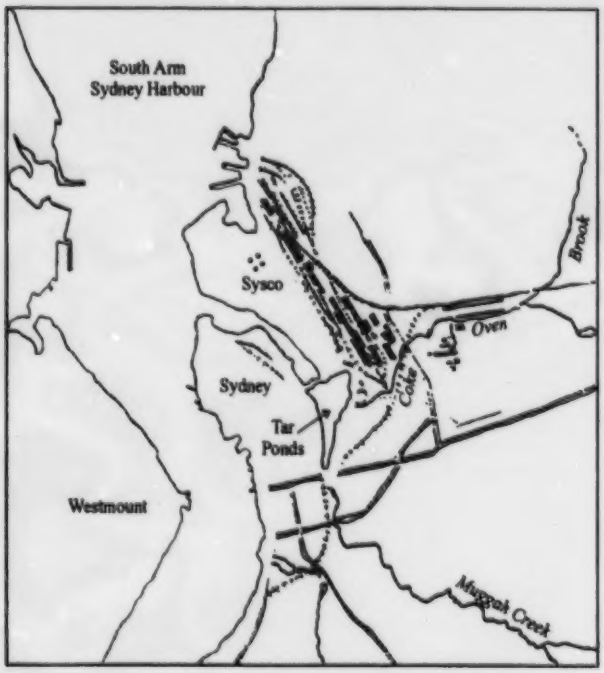


Figure 3.21. Detail of South Arm Sydney Harbour, showing location of the City of Sydney and the Sydney Steel Corporation (from Matheson et al. 1983).

Apart from the industrial and urban inputs to the inner harbour, a coal treatment, mining and wash operation (Princess colliery) occurs on the western coast of the Harbour near the mouth and discharges effluent containing elevated concentrations of dissolved iron into Sydney Harbour (Day *et al.* 1979). Levels of metals other than iron in coal mine effluents are not a particular concern (Hildebrand 1982).

3.4.5 Occurrences of Chemicals in Water, Sediments and Biota

The waters, sediments and biota of Sydney Harbour have been significantly impacted by a wide range of contaminants arising from industrial and municipal sources in the area. Sediments are contaminated with organic carbon, metals, PAHs, hydrocarbons, and other organic chemicals; waters with PAHs; lobster with PAHs and PCBs; and mussels with PAHs and metals.

Contamination is focused in South Arm, where the City of Sydney is situated and where Muggah Creek enters the Harbour. Various studies have examined contamination in Sydney Harbour, the majority focusing on impacts of releases from Muggah Creek and the Sydney Tar Ponds (see text box, page 87), but several have dealt with other sources of contamination, and evaluations of sediments prior to dredging and disposal activities. It has not been attempted by any study, however, to link separate major contaminant sources in the Harbour, to the various chemical loadings found in the area. Levels of contaminants in Sydney Harbour and their significance in relation to other areas are discussed in the following sections. Harbour divisions used in subsequent discussions are presented in Figure 3.22.

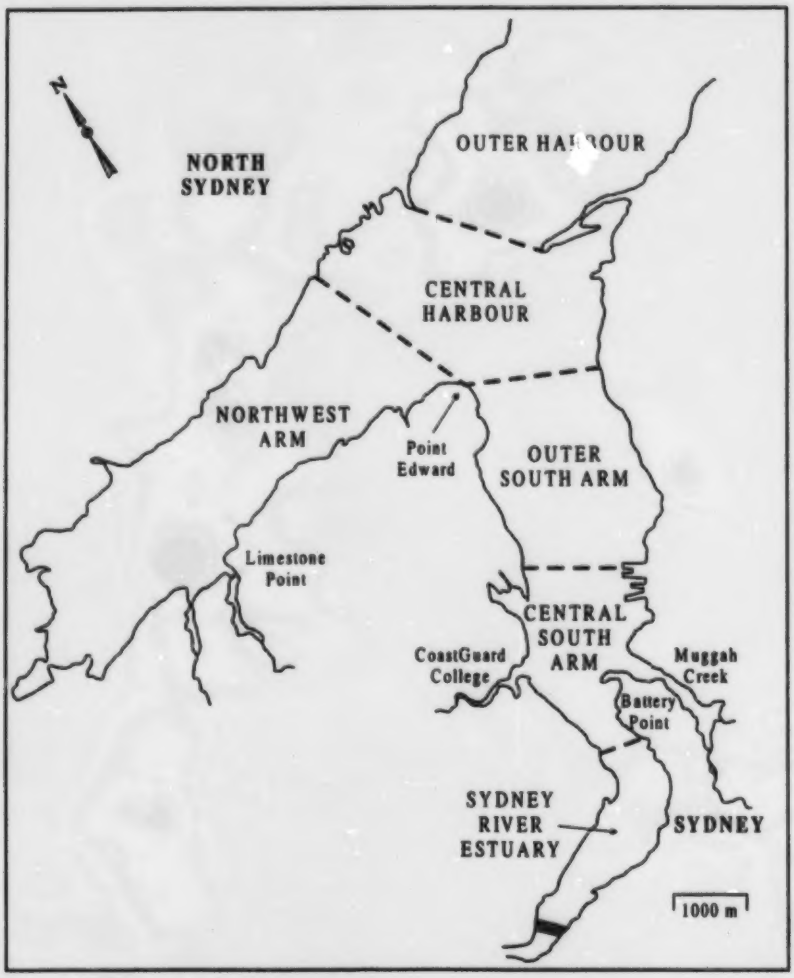


Figure 3.22. Sydney Harbour divisions.

Water

Concentrations of PAHs in water from Sydney Harbour have ranged from 0.1 to 1.0 µg/L, ranking among the highest found in surface, harbour, and estuarine waters in Atlantic Canada (O'Neill and Kieley 1992). One sample from Sydney Harbour exceeded the maximum acceptable concentration for the PAH compound benzo(*a*)pyrene dissolved in drinking water of 0.01 µg/L (CCREM (1987), Guidelines for Canadian Drinking Water Quality). There are no other guidelines for PAH concentration in natural waters, and although the guideline relates to human consumption, it suggests a level that could effect biological organisms under prolonged exposure. The lack of measurements of either organic or inorganic contaminants in water, and absence of information on their distribution in Sydney Harbour is presently a major data gap (Vandermeulen 1989).

Sediments

Sediments in South Arm of Sydney Harbour are the most contaminated of the Harbour in terms of a range of contaminants including PAHs, PCBs and various metals, in part due to the proximity of the major sources—the Tar Ponds and the City of Sydney—as well as the tendency of fine particles and associated contaminants to deposit.

Sediment concentrations of PAHs are highest within the estuarine portion of Muggah Creek, decreasing towards South Arm, while levels in South Arm have PAH concentrations elevated over those in the rest of the harbour (Matheson *et al.* 1983; Packman *et al.* MS; and Kieley *et al.* 1988; JWEL-IT Joint Venture 1996; Ernst *et al.* 1999). PAHs generally above 100 µg/g (up to 2,800 µg/g) dry weight have been measured at the mouth of Muggah Creek and vicinity, while levels in the outer harbour are less than 1 µg/g (Figures 3.23 & 3.24, Table 3.18).

SYDNEY TAR PONDS AND MUGGAH CREEK—THE MAJOR CONTAMINANT SOURCE IN SYDNEY HARBOUR

Muggah Creek and the Sydney Tar Ponds are the major sources of chemical contamination in Sydney Harbour. The Creek drains more than 38 square kilometres, including the City of Sydney, and has some twenty-nine municipal and industrial outfalls. The 'Tar Ponds' is a wetland situated on Muggah Creek adjacent to the steel plant. Below the tar ponds, where it discharges into South Arm, Muggah Creek becomes a partly tidal channel which is also highly contaminated (Figure 3.21). The Sydney Tar Ponds is considered to be one of the most severely contaminated hazardous waste sites in Eastern Canada, and the largest chemical waste site in Canada (Eaton *et al.* 1994). Outflow through Muggah Creek is the main source of a range of chemical contaminants, but principally PAHs, to Sydney Harbour.

The Tar Ponds have acted as a settling basin for steel mill and coking oven wastes, trapping sediments contaminated with PAHs and other chemicals, and leading to extremely high concentrations in sediments there of from 600 to 30,000 µg/g (3%) total PAH by weight (Vandermeulen 1989). Levels in sediments in the estuarine portion of Muggah Creek (which reach 2,800 µg/g) are a hundred times lower than levels found in the Tar Ponds, but are well above levels which are hazardous to biological organisms (levels of 2.5 µg/g total PAH in sediments require testing for toxicity under the Canadian Environmental Protection Act Ocean Disposal provisions). Metal concentrations, in contrast, are only slightly elevated in Tar Ponds sediments (Matheson *et al.* 1983).

Although coking activities ceased at the adjacent steel plant in the mid-1980s, the Tar Ponds remain as a massive potential source of contamination to Sydney Harbour. A 1989 study placed the continued flow of PAHs into South Arm from Muggah Creek at 770 kg/year (P. Lane and Associates 1990). The Muggah Creek system (including the Tar Ponds) has been reported to contain approximately 765,000 cubic metres of contaminated sediments, holding between 2 and 4 million kg of PAH material (Vandermeulen 1989; O'Neill and Kieley 1992), as well as other organic chemicals, among which PCBs are the greatest concern. An estimated 45,000 cubic metres of sediment having concentrations greater than 50 µg/g PCB are present in the Tar Ponds. The influence of the Sydney Tar Ponds is seen in the high levels of many hazardous chemicals which occur in Muggah Creek intertidal sediments (Hutcheson *et al.* 1986, Table 3.19).

	PAHs				PCBs
Year	1981	1983	1986	1995	1995
Location	Total PAH Concentration (µg/g dry weight)				PCB (µg/g) dry weight.
Sydney River [1]	16.0 - 79.0	29.7 - 323.0	4.2 - 190	1.1 - 58.6	not detected - 21.9
Central South Arm [2]	41.0 - 2,800.0	41.6 - 2,102.0	6.1 - 270	4.4 - 178.4	0.05 - 2.43
Outer South Arm [3]	13.0 - 750.0	8.5 - 179.3	3.3 - 120	3.5 - 31.7	trace - 1.0
Northwest Arm [4]	2.5 - 8.2	0.7 - 19.0	0.31 - 66	0.4 - 4.3	0.002 - 0.03
Outer Harbour [5]	0.13 - 10.0	12.9 - 18.0	0.0029 - 3.0	0.05 - 3.2	not detected
Reference	Matheson *et al.* 1983	Packman *et al.* MS	Kieley *et al.* 1988	JWEL-IT Joint Venture (1996)	JWEL-IT Joint Venture (1996)
Corresponding stations in Matheson *et al.* (1983) 1. Stations 36-43 2. Stations 26-35 (includes mouth of Muggah Creek) 3. Stations 18-25 4. Stations 8-17 5. Stations 1-7					

Table 3.18. Concentrations of polynuclear aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) in sediments from Sydney Harbour. Harbour subdivisions from Vandermeulen (1989). Locations shown in Figure 3.22.

Contaminant	Concentration (ng/g dry weight)		
	Mouth of Muggah Creek	Middle of Muggah Creek Estuary	Adjacent to Causeway Downstream of Tar Ponds
Organic Contaminants			
Total PAH	5.5	142	911
Benzo(a)pyrene	0.59	12	68
PCB	20	1,730	52,000
Total Chlorinated Pesticides	0.99	17	–
Total Chlorophenols	not detected	307	18.6
Total Phthalate Esters	80	7,100	6,080
Metals			
Total major metals	174,200	283,790	193,800
Total trace metals	>1,500	13,760	1,820
Arsenic	33	60	33
Cadmium	< 0.5	15.8	0.9
Chromium	45	287	60
Copper	341	1,240	220
Lead	627	1,070	488
Mercury	0.18	3.0	0.95
Zinc	296	10,500	833

Table 3.19. Contaminants in intertidal sediments from Muggah Creek, downstream of the Sydney Tar Ponds (from Hutcheson *et al.* 1986).

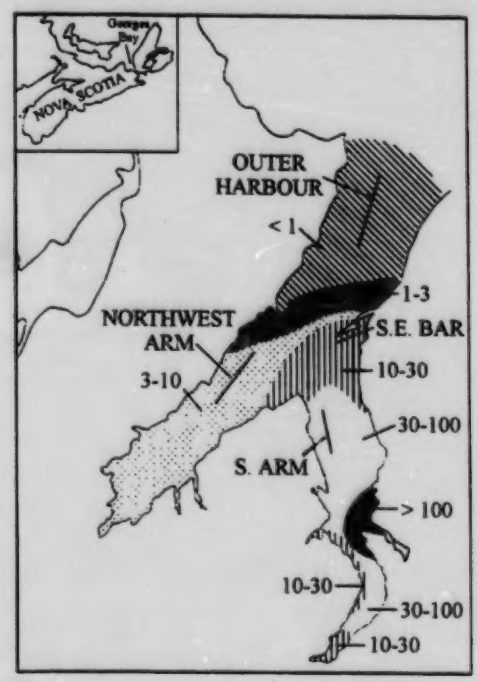


Figure 3.23. Map of Sydney Harbour showing total PAH concentrations (µg/g dry wt) in surface sediments in 1981 (redrawn from Vandermeulen 1989).

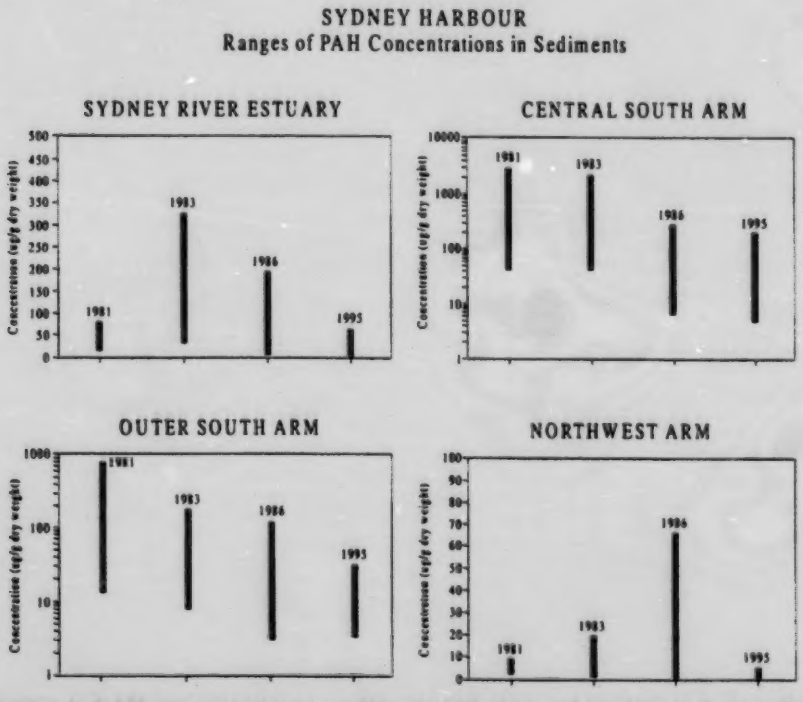


Figure 3.24. Changes in PAH concentrations in sediments with time and location in Sydney Harbour. For sources, see text and Table 3.18.

The high concentration of PAHs in sediments at the mouth of Muggah Creek, measured in 1981, is the highest reported for a range of industrial and contaminated marine sites around the world (Matheson *et al.* 1983; Gearing *et al.* 1991) (Table 3.12). Levels in the 1986-1995 period were substantially lower and were roughly similar, suggesting that concentrations have levelled off, although South Arm continues to have the highest concentrations (Figure 3.24). Dissipation of PAH concentrations could occur as a result of dissolution, degradation, and transport of PAHs with resuspended sediments, combined with reduced inputs from Muggah Creek.

South Arm also has some of the highest trace metal levels of the Harbour (Tables 3.20 & 3.21). In 1983, concentrations of mercury, copper, lead and zinc were highest in the inner to central portions of South Arm (the portions most influenced by the City of Sydney and Muggah Creek), while cadmium showed no particular trend (Packman *et al.* MS) (Figures 3.25 & 3.26, Tables 3.20 & 3.21). Except for sediments from Northwest Arm and the Outer Harbour, metal concentrations were above background levels for Nova Scotia and Atlantic coastal sediments (Table 3.20) (Loring *et al.* 1996) (see also Table 1.3), indicating anthropogenic contamination. Present metal concentrations continue to be elevated in South Arm (1995) compared with the rest of Sydney Harbour, although levels declined in the 1983-1995 period (Tables 3.20 and 3.21; Figure 3.25; JWEL-IT Joint Venture (1996) and also summarized in Ernst *et al.* (1999)). Current levels in South Arm exceed background concentrations (Loring *et al.* 1996), but levels in Northwest Arm and the Outer Harbour are comparable to background concentrations.

Table 3.20. Concentrations of heavy metals in sediments from Sydney Harbour in 1983 (from Packman *et al.* unpublished MS). Harbour subdivisions from Vandermeulen (1989), shown in Figure 3.22.

Metal	Cadmium	Copper	Mercury	Lead	Zinc
Location	Concentration (µg/g dry weight)				
Sydney River [1]	0.3 - 1.8	48.2 - 190.0	0.2 - 1.5	167.0 - 874.0	220.0 -1,026.0
Central South Arm [2]	0.2 - 0.8	28.6 - 169.0	0.1 - 16.8	44.2 - 408.0	214.0 - 776.0
Outer South Arm [3]	< 0.1 - 1.3	11.6 - 62.7	0.05 - 0.6	17.5 - 275.0	92.9 - 494.0
Northwest Arm [4]	0.2 - 0.7	9.0 - 40.0	0.04 - 0.2	10.4 - 69.7	73.4 - 206.0
Outer Harbour [5]	0.2 - 1.0	16.9 - 19.4	0.06 - 0.2	10.6 - 10.9	73.6 - 83.9
Background for Nova Scotia Inlets and Atlantic Coastal Waters (Loring *et al.* 1996.	3	40	1	40	150

Corresponding stations in Matheson *et al.* (1983)
1. Stations 36-43
2. Stations 26-35; (includes mouth of Muggah Creek)
3. Stations 18-25
4. Stations 8-17
5. Stations 1-7

Table 3.21. Concentrations of heavy metals in sediments from Sydney Harbour in 1995 (from JWEL-IT Joint Venture 1996). Harbour subdivisions from Vandermeulen (1989), shown in Figure 3.22.

Metal	Cadmium	Copper	Mercury	Lead	Zinc
Location	Concentration (µg/g dry weight)				
Sydney River [1]	nd (LQ=0.5)	23.6 - 141	Not Determined	52.1 - 278	10.2 - 565
Central South Arm [2]	nd (LQ=0.5)	4.7 - 136	Not Determined	20.5 - 221	93.8 - 367
Outer South Arm [3]	nd (LQ=0.5)	24.7 - 43.8	Not Determined	48.4 - 171	118 - 257
Northwest Arm [4]	nd (LQ=0.5)	7.3 - 38.8	Not Determined	10.2 - 83.1	41.3 - 140
Outer Harbour [5]	nd (LQ=0.5)	1.0 - 30.9	Not Determined	nd - 28.2	25.8 - 89.5
Background for Nova Scotia Inlets and Atlantic Coastal Waters (Loring *et al.* 1996)	3	40	1	40	150

nd = not detected
LQ = Limit of Quantitation
Corresponding stations in Matheson et al. (1983)
1. Stations 36-43
2. Stations 26-35; (includes mouth of Muggah Creek)
3. Stations 18-25
4. Stations 8-17
5. Stations 1-7

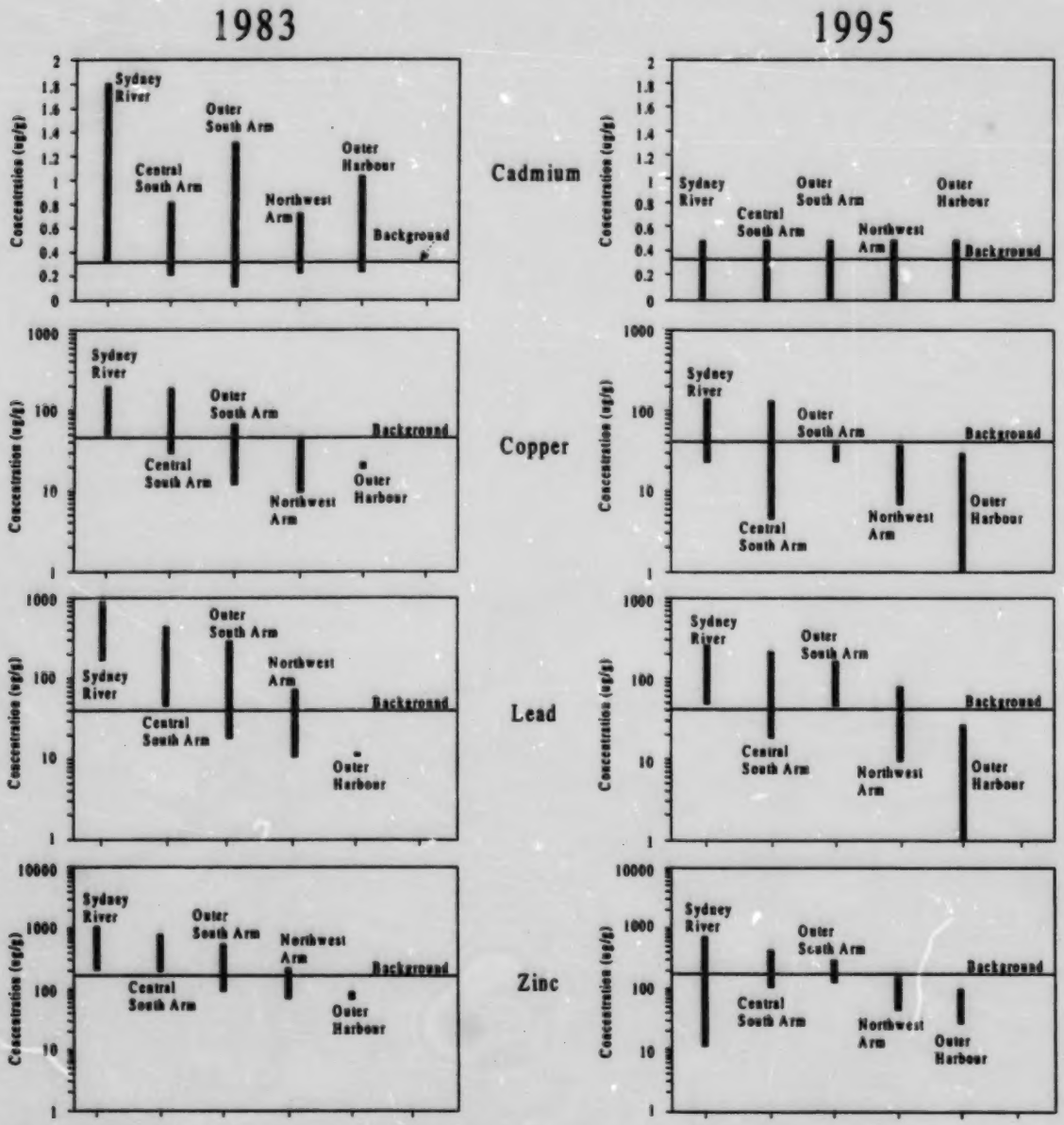


Figure 3.25. Range of sediment concentrations of metals in Sydney Harbour, 1983 versus 1995 (drawn from data in Packman *et al.* MS and JWEL-IT Joint Venture, 1996) (see Tables 3.20 and 3.21).

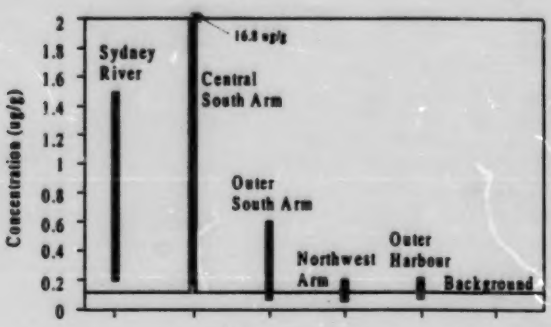


Figure 3.26. Range of sediment concentrations of mercury in Sydney Harbour, 1983 (drawn from data in Packman *et al.* MS and JWEL-IT Joint Venture, 1996) (see Tables 3.20 and 3.21).

Sydney Harbour sediments are also significantly contaminated with PCBs, showing highest levels in South Arm, with highest concentrations in 1995 occurring above Muggah Creek (Table 3.18; JWEL-IT Joint Venture 1996). In the early 1980s, elevated levels (up to 1,934 ng/g) were found at the mouth of South Arm (Table 3.22, OceanChem 1985). Many of these levels are above the Canadian ocean dumping guideline of 100 ng/g, and are well above the interim Canadian sediment quality guideline for protection of marine life (21.5 ng/g) (Environment Canada 1995). Elsewhere in the Harbour, PCBs have not been detected or occur at background levels (Table 3.18) (JWEL-IT Joint Venture 1996) (see Section 1.3). PCBs have been identified as a major contaminant of Muggah Creek and Sydney Tar Ponds sediments, which are probably the main sources in the area. Few measurements and no time series are available to assess the full extent of PCB contamination in the Harbour.

Table 3.22. Contaminant levels in sediments sampled adjacent to wharves and coastal structures in Sydney Harbour (from OceanChem 1986).

Location	North Sydney Marine Railway (1977)	South Bar (1982)	Point Edward (Crawley Creek) and Muggah Creek Mouth (1982)
Trace Metals			
Mercury (mg/kg)	117	0.002 - 0.003	0.49 - 3.96
Cadmium (mg/kg)	0.5	0.42 - 0.45	0.45 - 1.22
Copper (mg/kg)	890	44.1 - 50.2	47.7 - 117
Lead (mg/kg)	430	67.8 - 86.9	88.9 - 1124
Zinc (mg/kg)	1240	135 - 170.0	161 - 582
Organic Contaminants			
PCB (total, µg/kg)	931	17.9 - 18.3	10.4 - 1933.9
DDT (total, µg/kg)	200	< 5.0	up to 360.41
Hydrocarbons			
Oil and Grease (mg/kg)	468	11.4 - 72.4	<0.5 - 40,512 [1]
[1] likely includes PAHs.			

Heterocyclic aromatic hydrocarbons (HACs, combustion by-products similar to PAHs) have been found in sediments throughout South Arm at concentrations ranging from 10 to 5,200 ng/g dry weight. Their concentrations also decrease with distance from Muggah Creek (Kieley *et al.* 1988), and the compounds rarely occur outside South Arm. The predominant HACs in Sydney Harbour are carbazole, acridine, 5,6-benzoquinoline, 7-anthracene carbonitrile, 7-methyl quinoline, and 7,8-benzoquinoline (Kieley *et al.* 1988), all of which are likely to have been introduced from Muggah Creek.

Intertidal sediments in Muggah Creek below the Tar Ponds also contain a range of chemical contaminants, including PCBs, phthalate esters, chlorophenols and chlorinated organics such as

dieldrin (0.07 to 1.5 ng/g), heptachlor epoxide (not detectable to 13 ng/g) and trans-chlordane (not detectable to 2.5 ng/g) as well as p,p' DDT and Mirex (Hutcheson *et al.* 1986). Concentrations of PAHs and various organic contaminants and trace metals in intertidal sediments decline away from the tar ponds towards the mouth of Muggah Creek (Vandermeulen 1989) (Table 3.19). Some levels of dieldrin and chlordane in these sediments are above interim Canadian sediment quality guidelines (Environment Canada 1995).

Elevated concentrations of various contaminants occur in sediments near wharves and piers and in other high activity areas. Several such locations sampled in Sydney Harbour have levels of cadmium, mercury and PCBs above Canadian ocean dumping guidelines, and the Harbour ranked among problem harbours for dredging and maintenance purposes based on concentrations of those contaminants in the early 1980s (Figure 3.4; OceanChem 1985). Sediment levels of various contaminants at several of these locations are presented in Table 3.22 (OceanChem 1985).

Sydney Harbour also has elevated concentrations of petroleum hydrocarbons in sediments. In 1978, levels were elevated above those found in many Atlantic harbours and were above typical backgrounds. Nearshore sediments at Sydney/North Sydney averaged 25.5 μg/g dry weight (range from 1.6 to 81.4 μg/g), above the 10 μg/g or less found in the majority of harbours in Atlantic Canada, and 2-3 times lower than for harbour sediments in other major industrial centres such as Point Tupper (Canso Strait) and Halifax Inlet (Levy *et al.* 1988) (Sections 3.3.5 & 3.5.5). Similar levels were found in the early 1980s (Table 3.22) (OceanChem 1985); no recent published measurements of petroleum hydrocarbon concentrations in Sydney Harbour sediments are available.

Tributyltin has also been found in Sydney Harbour sediments at low concentrations (0.01 μg/g) (Maguire *et al.* 1986).

Biota

Lobster—It was the discovery of high concentrations of PAHs in lobster in Sydney Harbour in 1980 that brought attention to the significant contamination problems there (Sirota *et al.* 1983 & 1984). Concentrations in lobster meat of the carcinogen benzo(*a*)pyrene ranging from 8 to 40 ng/g were significantly above the recommended level for foodstuffs in Canada (1 ng/g benzo(*a*)pyrene wet weight) (Uthe 1979, from Eaton *et al.* 1986; Sirota *et al.* 1983; 1984), leading to a closure of the lobster fishery in South Arm. Concentrations of total PAHs in lobster digestive gland have been subsequently used as the principal means of monitoring PAH levels in lobster, and form the basis for most comparisons[4]. The range on concentrations on coastal areas of Nova Scotia; including Sydney Harbour, are shown in Figure 1.2.

Concentrations of total PAHs in lobster digestive gland have fallen significantly since reaching peak levels in the early 1980s, but are still a concern. Levels in 1981-1982 ranged from 3,780 to 88,150 ng/g, wet weight (Table 3.23; Figure 3.27), highest in South Arm, and significantly above

[4] Concentrations of contaminants are measured in digestive gland for ease of analysis because higher concentrations are typically found there than in other body parts.

levels elsewhere in the harbour and background concentrations (Table 3.24), reflecting the role of Muggah Creek as the principal point source. Levels in South Arm lobster fell in the mid-1980s, although they continued to be significantly elevated over those in other parts of the harbour and have levelled off to present (King *et al.* 1993; Uthe and Musial 1986; JWEL-IT Joint Venture 1996; Ernst *et al.* 1999)) (Tables 3.24 & 3.25). Information on PAH composition suggests that the decline between 1982 and 1984 was due mainly to decreases in the individual PAH compounds fluoranthene, pyrene and benz[*a*]anthracene (Table 3.25), two of which (fluoranthene and pyrene) appear to be linked to the reduced input of PAHs into South Arm from Muggah Creek (Uthe and Musial 1986).

Location	Average PAH Concentration (ng/g wet weight)		
	1981	1982	1995
South Arm	75,409 (57,239 - 88,146)	97,960 (73,303 - 128,314)	8,785 (3,900 - 13,670)
Northwest Arm	11,605 (11,424 - 11,785)	19,560 (16,542 - 22,577)	–
South Bar (Sydney Harbour)	15,443 (8,697 - 22,700)	8,737 (5,346 - 10,866)	4,560 (1 sample)
Swivel Point (mouth of harbour)	16,661 (16,206 - 17,115)	4,303 (3,777 - 4,829)	–
Petrie Point (mouth of harbour)	13,285 (11,607 - 14,962)	10,670 (5,740 - 18,704)	–
Outer Harbour and Off Harbour Mouth	–	–	201 (nd - 2,210)
Mira Bay (clean site)	142 (97.2 - 186.8)	–	–
1. Sirota *et al.* 1983 & 1984; JWEL-IT Joint Venture 1996.			

Table 3.23. Polycyclic aromatic hydrocarbon (PAH) concentrations in the digestive gland of lobster (*Homarus americanus*) from Sydney Harbour, Nova Scotia in 1981-1982 and 1995 (from Sirota *et al.* 1983 & 1984; JWEL-IT Joint Venture 1996).

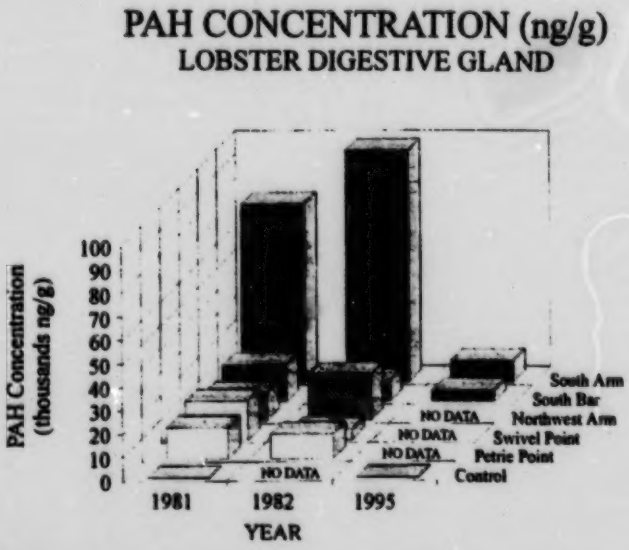


Figure 3.27. Polycyclic aromatic hydrocarbon (PAH) concentrations in digestive gland of lobster (*Homarus americanus*) comparing changes with time and location in Sydney Harbour (data from Sirota *et al.* 1983 & 1984; JWEL-IT Joint Venture 1996 (see also Table 3.18).

Table 3.24. Polycyclic aromatic hydrocarbons (PAH) concentrations in digestive gland of lobster (*Homarus americanus*) and whole animals of blue mussel (*Mytilus edulis*) from coastal areas of northeastern Cape Breton Island and Guysborough, Nova Scotia, 1981-1982 (from Sirota *et al.* 1984).

Location	PAH Concentration (ng/g wet weight)
Lobster	
Point Aconi	68
Black Point	1,561
Low Point (mouth of Sydney Harbour)	3,297
Lingan Bay	490
Glace Bay	1,572
Morien Bay	1,185
Port Morien	584
Guysborough (mainland Nova Scotia)	2,104
Louisbourg	907
Mira Bay (uncontaminated control)	142
Mussels	
Bridgeport Basin	271 - 370
Homeville Bridge	57 - 986
Alder Point	267 - 3,291
Seal Island	14 - 1,024

Table 3.25. PAH profiles in digestive gland of lobster (*Homarus americanus*) from South Arm, Sydney Harbour in 1981, 1982, 1984, and 1991.

	Concentration (ng/g wet weight)			
Year	1981 [1]	1982 [2]	1984 [2]	1991 [3]
Phenanthrene	9,493	4,576	NR [4]	1,140
Fluoranthene	7,210	13,800	4,730	4,660
Pyrene	8,455	11,125	3,045	3,310
Triphenylene	20,300	29,200	NR [4]	A [5]
Benz[a]anthracene	9,390	25,350	956	940
Chrysene	7,760	641	1,005	1,260
Benzo[e]pyrene	3,700	2,795	2,210	520
Benzo[b]fluoranthene	943	3,140	1,285	1,080
Benzo[k]fluoranthene	230	798	658	571
Benzo[a]pyrene	410	1,180	986	720
Benzo[ghi]perlyene	1,018	624	346	200
Indeno[1,2,3-cd]pyrene	1,610	632	709	33
Total PAH (excluding phenanthrene and triphenylene)	45,617	64,185	15,930	13,294
Total PAH	75,409	97,960	–	14,434

1. Sirota *et al.* (1984);
2. Uthe and Musial (1986);
3. King *et al.* (1993);
4. not reported;
5. included with chrysene.

Furans (dioxins and furans are cancer-causing by-products of incineration and chlorine bleaching in the pulp and paper industry and in pentachlorophenol wood preservative), have been found at approximately 10 times background in the digestive glands of lobster from South Arm (Clement *et al.* 1987) (Table 3.26), possibly through contamination of the local environment with pentachlorophenol. The most toxic of the compounds, TCDF (2,3,7,8 tetrachlorodibenzofuran) was present at the highest concentrations, followed by the less-toxic dioxins (hepta- and octochlorodibenzo-*p*-dioxin) and Pentachlorodibenzofuran (PCDF) at lower levels. Levels of both furans and dioxins were above background concentrations found in lobster at an unspecified 'clean site' off northeast Cape Breton, where only the furans tetrachlorodibenzofuran (TCDF) and pentachlorodibenzofuran (PCDF) were detected (Table 3.26). Any detectable levels of these compounds in biological organisms is considered to be a concern.

Table 3.26. Chlorinated dibenzo-p-dioxins and dibenzofurans in lobster digestive glands from South Arm, Sydney Harbour

Site	South Arm	Outer Harbour	"Clean Site"
	Concentration (pg/g wet weight)		
Dioxins			
Tetrachloro-p-dibenzo dioxin (TCDD)	ND	ND	ND
Pentachloro-p-dibenzo dioxin (PCDD)	ND	ND	ND
Hexachloro-p-dibenzo dioxin	ND	ND	ND
Heptachloro-p-dibenzo dioxin	8.5	ND	ND
Octachloro-p-dibenzo dioxin	2	ND	ND
TOTAL	10.5	ND	ND
Furans			
Tetrachlorodibenzofuran (TCDF)	445	48	61
Pentachlorodibenzofuran (PCDF)	44	ND	4
Hexachlorodibenzofuran	ND	ND	ND
Heptachlorodibenzofuran	ND	ND	ND
Octachlorodibenzofuran	ND	ND	ND
TOTAL	490	48	65

Lobster in South Arm have also been shown to have elevated concentrations of PCBs, compared with lobster in other areas of the Harbour (JWEL-IT Joint Venture 1996). Trace amounts were detected in muscle of lobster captured in South Arm at Muggah Creek, but not at South Bar and in the outer portions of the Harbour, while concentrations in digestive gland were highest in South Arm (2.8 - 7.6 μg/g) and at South Bar (4.8 μg/g), versus an average of 0.30 (0.18 - 0.86 μg/g) in the outer harbour and approaches (JWEL-IT Joint Venture 1996). Based on muscle levels of PCBs, South Arm lobster appear to be acceptable for human consumption using the 2 μg/g Health and Welfare Canada guideline for fish products. Levels in lobster digestive gland in South Arm are comparable to those found in Halifax Harbour (Uthe *et al.* 1989; Table 3.13).

Mussels—Blue mussels (*Mytilus edulis*) have also shown significantly elevated PAH concentrations in South Arm compared with the rest of the Harbour and control areas. Peak concentrations reached 38,875 and 13,955 ng/g wet weight in 1981 and 1982 respectively at South Bar (at the mouth of South Arm) compared with a range of from 14 to typically less than 1,000 ng/g in control areas (Sirota *et al.* 1984) (Table 3.24). Subtidal populations of *Mytilus edulis* and horse mussel (*Modiolus modiolus*) were subsequently monitored at a repeated sampling grid in Sydney Harbour from 1981 to 1995 (and are ongoing) to determine trends in PAH contamination (Table 3.27; Figure 3.28). Concentrations ranged from 4,100 ng/g wet weight on the coast south of Muggah Creek in 1981 to 230 ng/g in Northwest Arm (Matheson *et al.* 1983). Levels appear to have fallen between 1981 and 1986, but subsequently increased, and

1995 concentrations appear to be comparable to the more moderate levels found in the early 1980s (Table 3.27, Figure 3.28) (Kieley *et al.* 1988; JWEL-IT Joint Venture 1996; Ernst *et al.* 1999). Highest concentrations of PAHs continue to be found in South Arm mussels, and levels in other harbour areas are lower, and usually comparable to the control sites from the earlier studies. Most levels measured in these studies are well above average levels of total PAHs in mussels for United States coastal 'Mussel Watch' sites (Table 1.4) (O'Connor 1992).

Table 3.27. PAH concentrations in Sydney Harbour mussels (*Mytilus edulis* and *Modiolus modiolus*) in 1981, 1986 and 1995.

Tissue PAH Concentration (ng/g wet weight)				
Sample Station [1]	Location	Year		
		1981 [2]	1986 [3]	1995 [4]
M2	Sydney River	740	160	4,683
M4	Central South Arm, East Side (above Muggah Creek)	4,100	3,200	5,198
M5	Central South Arm, West Side (above Muggah Creek)	2,400	780	3,027
M6	Outer South Arm	480	230	1,614
M7	Northwest Arm	230	N.D.	1,369
M1	Outer Harbour	470	66	948

1. Stations from Kieley *et al.* (1988);
2. Matheson *et al.* (1983);
3. Kieley *et al.* (1988);
4. JWEL-IT Joint Venture 1996.

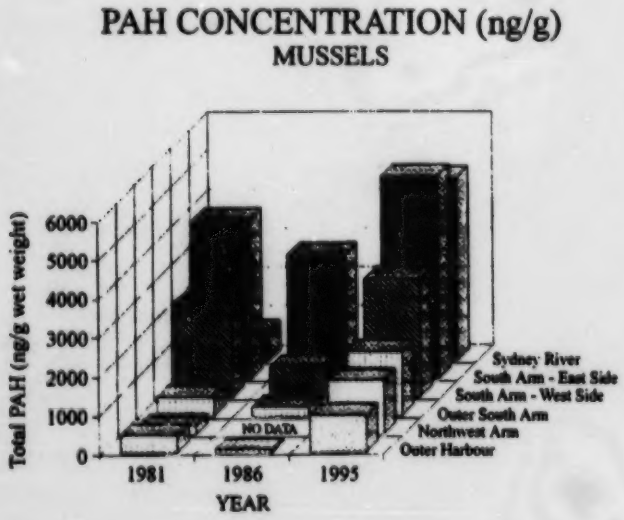


Figure 3.28. Polycyclic aromatic hydrocarbon (PAH) concentrations in tissues of mussels (*Mytilus edulis* and *Modiolus modiolus*) comparing changes with time and location in Sydney Harbour (data from Kieley *et al.* 1988; Matheson *et al.* 1983; JWEL-IT Joint Venture 1996) (see Table 3.27).

Intertidal mussels from Point Edward (mouth of South Arm) showed a low burden of metals and organic contaminants in a monitoring study conducted by Environment Canada in 1989 (Zenon Environmental Inc. 1989 MS) (Table 3.28). PAH concentrations were below the detection limit (less than 100 ng/g) for key PAH compounds, while concentrations of trace metals were generally elevated (allowing for wet weight/dry weight difference in measurements) compared to averages for mussels in United States coastal areas, and in the Gulf of Maine (O'Connor 1992; GMCME 1994) (See Table 1.4). Arsenic, cadmium, copper and zinc were higher and mercury was lower than in mussels from other developed inlets on the Atlantic coast (Tables 3.5, 3.14 and 3.29), and copper and mercury were higher than in mussels at an uncontaminated coastal site (Beaver Harbour) (Zenon Environmental Inc., 1989MS). Mussels sampled outside Sydney Harbour and analyzed for mercury and zinc, had mercury concentrations less than 206 ng/g dry weight and zinc from 100-150 μg/g dry weight (Cossa and Rondeau 1985; Cossa (1980) from Messieh and El-Sabh 1988), comparable to U.S. coastal averages (O'Connor 1992) (Table 1.4).

Table 3.28. Concentrations of various contaminants found in mussels from Point Edward (mouth of South Arm) in a survey of metals, volatile and semi-volatile organics, PAHs, chlorinated organics, pesticides and aromatic amines carried out by Environment Canada (Zenon Environmental Inc. 1989MS; G. Julien, Environment Canada, personal communication).

Contaminant	Concentration (µg/g wet weight)
Metals	
Arsenic	2.0 µg/g
Cadmium	1.6 µg/g
Chromium	0.24 µg/g
Copper	5.5 µg/g
Iron	150 µg/g
Lead	1.6 µg/g
Mercury	0.022 µg/g
Silver	less than 0.3 µg/g
Zinc	44 µg/g
Organics	
bis(2-ethylhexyl) phthalate [1]	0.26 µg/g
di-n-octyl phthalate [1]	not detected
methylene chloride	not detected
picloram [2]	less than 0.05 µg/g
Selected PAHs benzo(a)anthracene benzo(a)pyrene fluoranthene pyrene triphenylene	none detected (detection limit, < 0.1 µg/g)
1. plasticizer; 2. carboxylic acid pesticide.	

Table 3.29. Concentrations of various contaminants found in mussels from Canso in a survey of metals, volatile and semi-volatile organics, PAHs, chlorinated organics, pesticides and aromatic amines carried out by Environment Canada (Zenon Environmental Inc. 1989MS; G. Julien, Environment Canada, personal communication).

Contaminant	Concentration (µg/g wet weight)
Metals	
Arsenic	1.2 µg/g
Cadmium	0.37 µg/g
Copper	1.4 µg/g
Chromium	0.55 µg/g
Iron	120 µg/g
Lead	1.3 µg/g
Mercury	0.017 µg/g
Silver	less than 0.3 µg/g
Zinc	16 µg/g
Organics	
bis(2-ethylhexyl) phthalate1	not detected
di-n-octyl phthalate1	0.57 µg/g
methylene chloride	not detected
picloram2	less than 0.03 µg/g
Selected PAHs benzo(a)anthracene benzo(a)pyrene fluoranthene pyrene triphenylene	none detected (detection limit, < 0.1 µg/g)
1. plasticizer; 2. carboxylic acid pesticide.	

Other Organisms—Winter flounder (*Pseudopleuronectes americanus*) captured in areas of Sydney Harbour having the highest concentrations of PAHs in sediments, demonstrate the development of mixed function oxidases (MFOs) (enzymes which aid the organism in detoxifying contaminants, including hydrocarbons and PAHs). Occurrence of elevated concentrations of several of these related enzymes is generally greatest in fish caught in parts of the harbour which are more contaminated with PAHs (Vignier *et al.* 1994; Addison *et al.* 1994). Direct measurements of concentrations of PAHs in fish tissue have, nevertheless, not been reported.

A single study in the Sydney area looked at contamination in higher vertebrates. Great Blue Heron and Common Merganser from the Sydney area had elevated liver concentrations of PCBs and measurable concentrations of light aromatic hydrocarbons (lower alkyl benzenes and naphthalenes) characteristic of petroleum and gasoline (1.1 to 38.9 ng/g wet weight) (Busby 1992 from O'Neill and Kieley 1992).

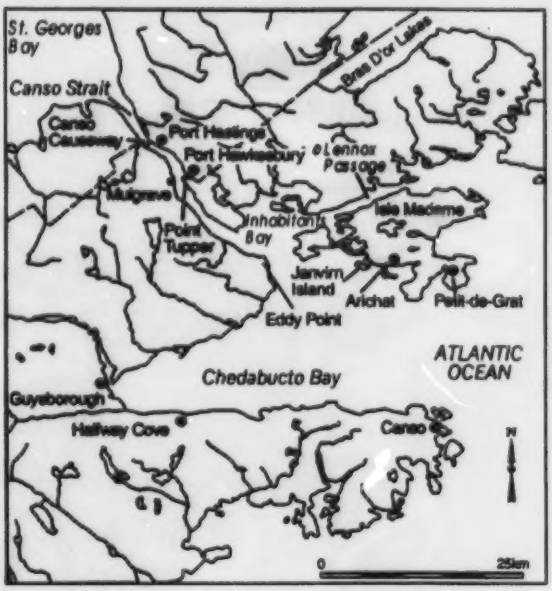
3.11 Summary and Conclusions

Sydney Harbour is an example of a coastal inlet impacted by a major uncontrolled pollution source, the Sydney Tar Ponds, but one also exposed to the range of contaminants typical of a major industrial, transportation and population centre. Major impacts have occurred in the Harbour, including significant contamination of waters, sediments and biota in South Arm with anthropogenic contaminants such as organic carbon, trace metals, PAHs and PCBs; physical/chemical changes including the occurrence of decreased oxygen levels in South Arm; and biological changes such as biochemical changes in fish, and changes in abundance and distribution of organisms (i.e. benthic animals). Contamination has also had a significant impact on an important commercial fishery for lobster, which is no longer carried out in South Arm. Despite the various impacts, the extent of contamination does not appear to extend beyond the Harbour, although the extent of current sampling does not allow the assessment of the full extent of its effects. Current efforts to remove the main source of PAHs through a clean-up of the Sydney Tar Ponds is likely to significantly improve conditions in Sydney Harbour, but a complete improvement will only come when changes are made which will reduce the levels of the full range of contaminants which currently enter it.

3.5. CANSO STRAIT AND CHEDABUCTO BAY

The narrow Canso Strait and Chedabucto Bay into which it opens on the Atlantic Ocean, separates the mainland of Nova Scotia from the Island of Cape Breton. Formerly an open passage and major waterway connecting the Atlantic with St. Georges Bay in the Gulf of St. Lawrence, the Canso Strait and Chedabucto Bay system was artificially closed by the construction in 1954 of a rock-filled causeway and locks (the Canso Causeway) at the northern end. The resulting ice-free port on the south side of the causeway was a catalyst for industrial development, and various industries established there, principally on the eastern shore of the Strait in the Port Hawkesbury area, often discharging significant quantities of effluents, and significantly altering the marine environment in the area.

The area also supports a significant population, located principally on the Canso Strait (Port Hawkesbury (population 3,990, 1991 census), Mulgrave (935) and Port Hastings (362)), but elsewhere spread thinly along the coast and concentrated in the many fishing ports on Chedabucto Bay—Arichat (886) and Pétit-de-Grat (454) on the northern margin; Canso (1,230), Dover (518) and Guysborough (494) on the south coast; and Louisdale (443), St. Peters (731), and River Bourgeois (459) on Lennox Passage and outer northern approaches (Figure 3.29).



Owing to local urban pollution and sewage, and marine vessel and fishing-related activity, the harbours of most of these ports are typically contaminated with a range of industrial compounds and contaminants, such as petroleum hydrocarbons, metals and PCBs. Thus, although industrialization has been a major factor in environmental contamination of the Canso Strait area, more-general and widespread practises related to human activity, as well as broad-scale contaminant patterns, have also been important.

Figure 3.29. Location map of Canso Strait and Chedabucto Bay.

3.5.1 Oceanography

Canso Strait south of the Canso Causeway is an inlet 18 km long and relatively narrow (0.8 to 2 km—typically 1.6 km), and having a U-shaped basin. Depth ranges along its length from a minimum of 44 m at Chedabucto Bay (Buckley *et al.* 1974) (Figure 3.30) to more than 60 metres (64 m maximum depth) in several seabed depressions in the vicinity of the Canso Causeway (Vilks *et al.* 1975; Gregory *et al.* 1993). North of the Causeway, the minimum depth in the Strait is 35 metres at the entrance to St. Georges Bay, while depth reaches 51 metres adjacent to the Causeway (Buckley *et al.* 1974).

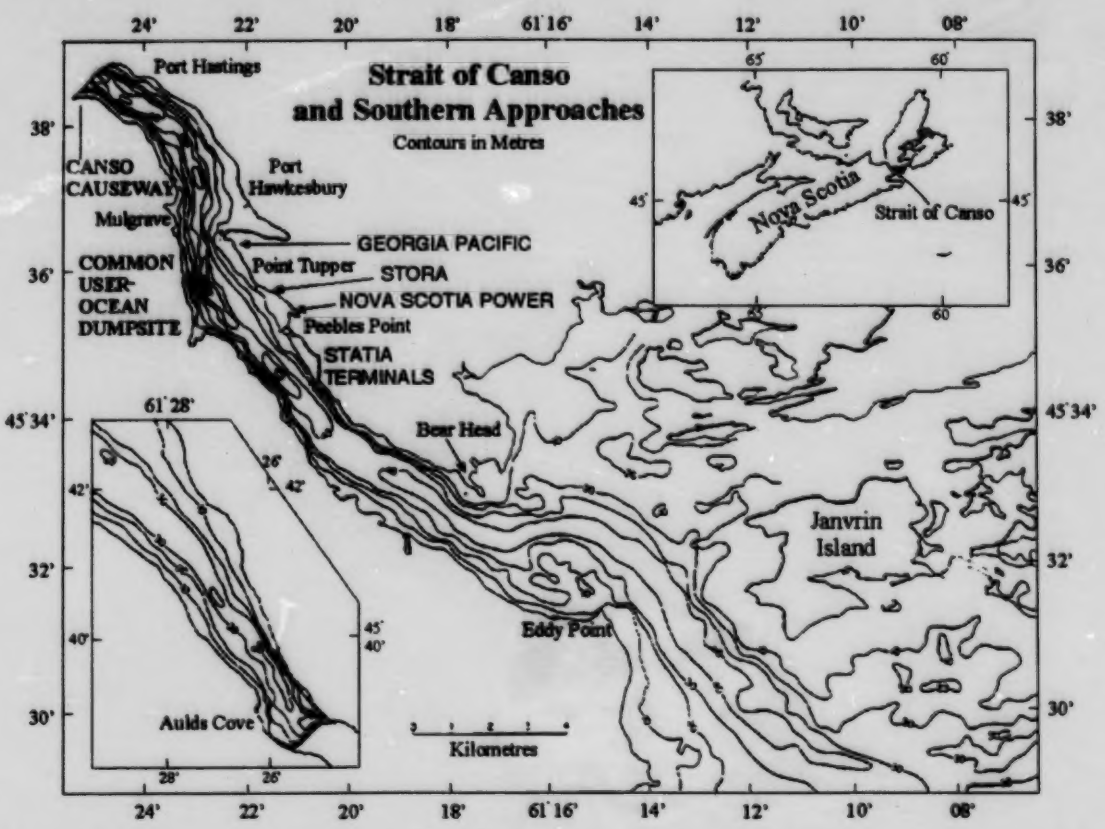


Figure 3.30 Bathymetry and key features of the Strait of Canso and approaches. Bathymetry from Buckley *et al.* 1974.

Chedabucto Bay, at the southeast end of the Canso Strait, is a broad, relatively shallow, embayment, approximately 16 km north-to-south and 35 km in east-west dimension, and open along the south and east to the Atlantic Ocean. A shallow shelf (less than 30 m) on the northern side contains a system of islands, of which the largest are Isle Madame and Janvirn Island, and several semi-enclosed bays and passages (Figures 3.29 and 3.30). Depth gradually increases from 30 metres in mid-bay to 90-100 m or more on the eastern margin, and reaches 80-90 metres in a trough on the south side of the bay.

Prior to construction of the Canso Causeway, the Strait supported a significant net flow of water (7,200 cubic metres per second) from St. Georges Bay (Drinkwater 1979), which was reduced virtually to zero after construction. The change significantly affected the oceanographic regime; the waters, formerly dominated by strong currents (up to 9.5 km/hr), shifted to a more passive fjord-type system, having weak currents (1-2 km/hour) dominated by winds (Lawrence (1973) from Buckley *et al.* 1974; Trites 1979a). The passage of ice from the Gulf was also eliminated, creating year-round ice-free conditions south of the Causeway and in Chedabucto Bay (Buckley *et al.* 1974; Messieh and El-Sabh 1988; McCracken 1979).

The waters of Canso Strait on the Atlantic side of the Causeway are typically highly stratified in summer. Temperature and salinity in the upper 20 metres reach more than 15 °C and less than 29 ppt respectively, while at bottom (deeper than 35 metres) are 3 to 7 °C and 31 ppt (Figure 3.31). A wind causing currents towards Chedabucto Bay along the Strait can cause significant upwelling in the upper reaches, bringing cold (3 °C) water to the surface (Buckley *et al.* 1974). In addition, the net movement of the surface water layer is thought to be down the Strait towards Chedabucto Bay, in response to the prevailing winds (Buckley *et al.* 1974), creating an estuarine-like circulation (in this case the surface water movement is driven by wind and not freshwater flow), in which a net flow in the deep water layer occurs inward, towards the head of the Strait. On the Gulf of St. Lawrence side of the Canso Causeway, the waters are less stratified, and water temperatures are higher in summer (Figure 3.32). Flushing time of the Strait is 8.6 days (Gregory *et al.* 1993).

IMPACTS OF INDUSTRIALIZATION IN THE STRAIT OF CANSO ON BIOLOGICAL COMMUNITIES

Biological communities generally establish if conditions in the physical/chemical environment are suitable and there is a source of organisms for colonization. Differences in community characteristics and component species from known natural conditions can be used to give an indication of the relative impact of environmental changes, in the case of the Strait of Canso, in sedimentation and water temperature regime and other anthropogenic impacts. In the Canso Strait/Chedabucto Bay system, several studies have been carried out on components of the biological system to use them as indicators of environmental change in the area including impacts of Causeway construction and industrialization in the Strait (Buckley *et al.* 1974; Vilks *et al.* 1975; Schafer *et al.* 1975; Scarratt and Associates 1994a). In general, the industrialized portions of Canso Strait have sparse biological communities in some areas (chiefly those severely contaminated with organic debris from pulp mill wastes), but relatively typical communities in other areas. The pulp mill wastes coincide with a biological 'barren zone' in which a low number of biological species and low overall abundance of a wide range of animal groups occurs (Buckley *et al.* 1974; Vilks *et al.* 1975; Schafer *et al.* 1975; Scarratt and Associates 1994a). Reduced abundance and diversity of organisms is also found in the vicinity of outfalls in the area (Scarratt and Associates 1994a).

In addition to impacts due to industrialization, the change in water temperature resulting from Causeway construction has resulted in changes in species composition of some biological communities of some biological groups. The change is best documented for species of foraminifers (a group of millimetre-sized protozoans usually having a calcareous shell). Species found on the Atlantic side of the Causeway are typical of cool, inner continental shelf waters (Vilks *et al.* 1975), while on the Gulf of St. Lawrence side, they are typical of warmer waters. Deeper in sediments on the Gulf of St. Lawrence side, however, are the remains of forms having cooler water preferences, reflecting the change in oceanographic conditions to warmer summer temperatures after construction of the Causeway.

Canso Strait and Chedabucto Bay were formerly a migration route for pelagic fish species such as Atlantic herring (*Clupea harengus harengus*) and mackerel (*Scombrus scombrus*) into the Gulf of St. Lawrence. At present, as in other coastal areas of the Atlantic Coast, mackerel move through the area seasonally although they no longer use the Strait to reach the Gulf (McCracken 1979). Likewise, herring which formerly moved through the Strait to the Gulf of St. Lawrence have been diverted to a route which takes them around northern Cape Breton. An extensive review of fisheries to determine impacts of Causeway construction, however, failed to identify any significant changes in fisheries landings for either species, or for any other commercial species, either in the southern Gulf of St. Lawrence or the Canso Strait/Chedabucto Bay system (McCracken 1979).

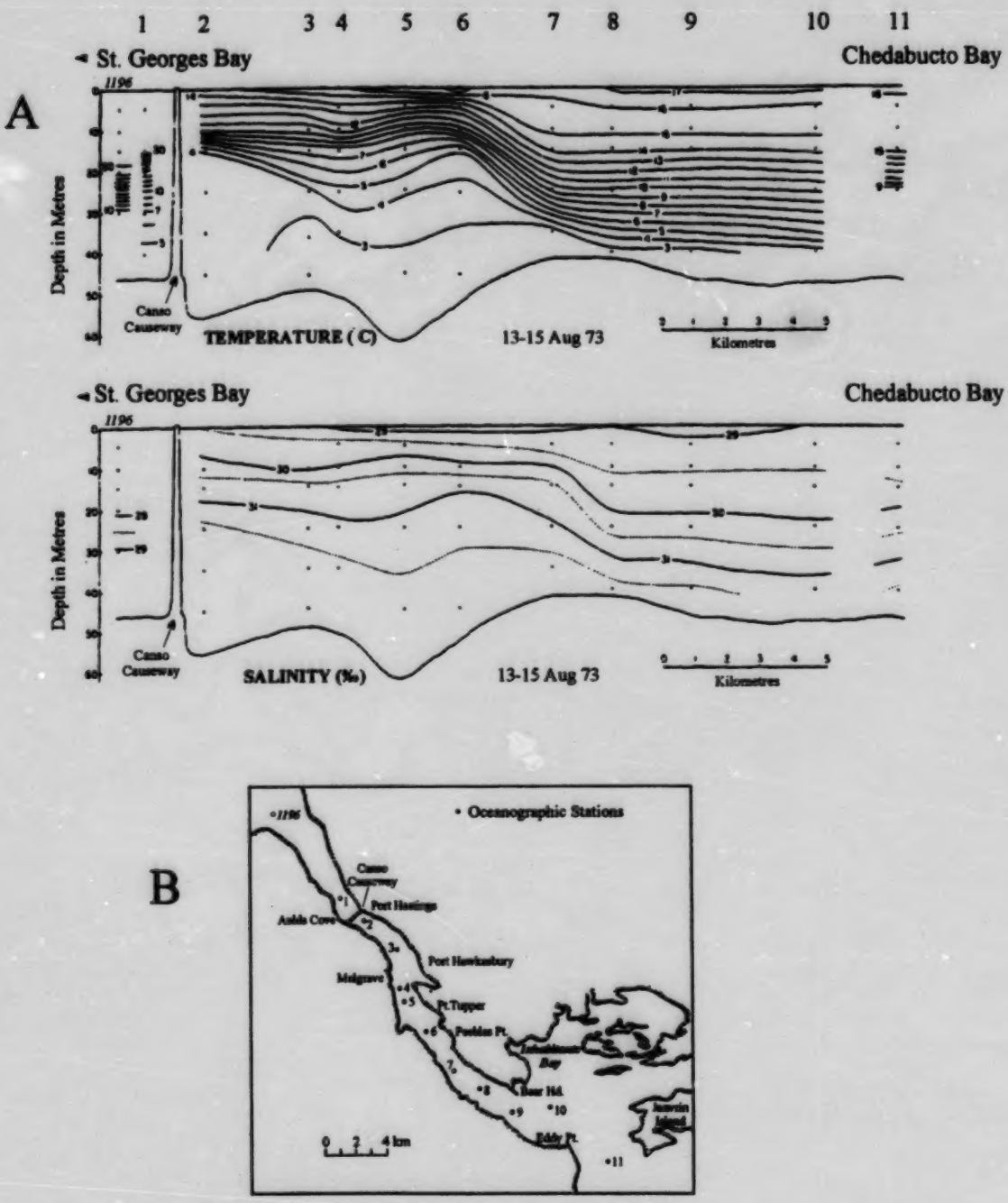


Figure 3.31. (A) Profile of temperature and salinity along the axis of the Strait of Canso during August 1973 (from Buckley *et al.* 1974). (B) Station locations.

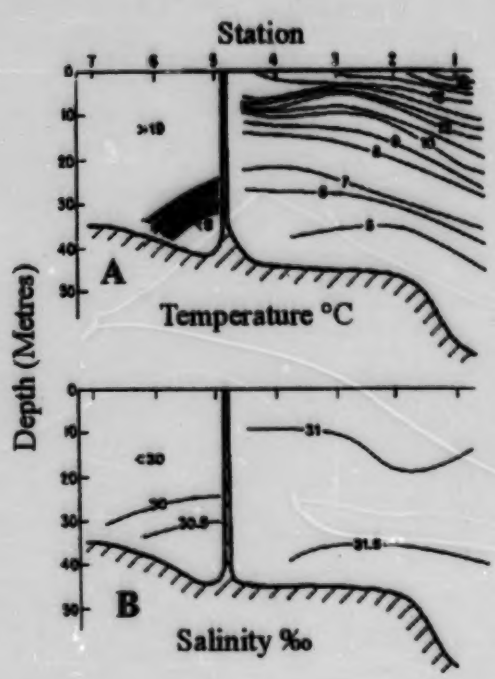


Figure 3.32. Distribution of temperature (°C) (A) and salinity ‰ (B) August 22, 1959, on both sides of the Canso Causeway, Strait of Canso (from Buckley *et al.* 1974).

The oceanography of Chedabucto Bay reflects conditions in the adjacent Atlantic Ocean waters and strongly affects Canso Strait south of the Causeway. Water column structure is similar to that in the Strait although surface salinity is higher (Figure 3.31). Tides in both Canso Strait and Chedabucto Bay are semidiurnal (twice per day) with a mean tidal range of 1.5 m (Owens and Bowen 1977). There is a net counterclockwise flow at all depths in Chedabucto Bay (Lawrence 1979) resulting in a 'flushing time' (from the northern entrance to the southern exit) of about 23 days. The main factor influencing flushing appears to be movements of water masses into the area, tidal exchange having a negligible effect (Lawrence 1979). The source of surface water in the area appears to be primarily Cabot Strait (Trites 1979b) as the result of the general southwesterly movement of the Nova Scotia Current along the coast. Although significant upwelling occurs along much of the Cape Breton coast, it is minimal in Chedabucto Bay (Trites 1979b).

Freshwater sources along the Strait include coastal watercourses, runoff, and the Inhabitants and Salmon Rivers, which enter at the head of Inhabitants Bay and in the Guysborough area respectively. The combined outflows of industries in the area also divert significant quantities of freshwater to the Strait, which probably result in a small salinity reduction in the surface layer (Buckley *et al.* 1974). In the early to mid-seventies, the Nova Scotia Forest Industries pulp mill on Canso Strait discharged an estimated 95 million litres/day of effluent (Day 1979). Annual freshwater discharge into Canso Strait is 82.5 cubic metres per second, peaking in April (Gregory *et al.* 1993).

The altered oceanographic regime and industrialization at the head of the Strait has also caused elevated levels of suspended particulate material in the waters south of the Causeway. In studies conducted in the 1970s, the waters of the Canso Strait contained significant levels of particulate matter, much of which arose from industrial and urban effluents (Buckley *et al.* 1974; Kranck and Sheldon 1979; MacLean *et al.* 1977) (Figure 3.33). In 1973, turbidity, particulate organic carbon (POC), and suspended particulate matter (SPM) in the surface 15 metres at the head of the Strait were higher than in deeper water—concentrations of POC and SPM were 4.3 and 4.0 mg/L, respectively, in surface waters, versus 0.9 and 0.7 mg/L in bottom waters (Buckley *et al.* 1974). Comparable present-day studies have not been carried out, although industries in the Strait still discharge a significant volume of effluents (Scarratt and Associates 1994a). Industrial inputs are discussed in greater detail later in this section.

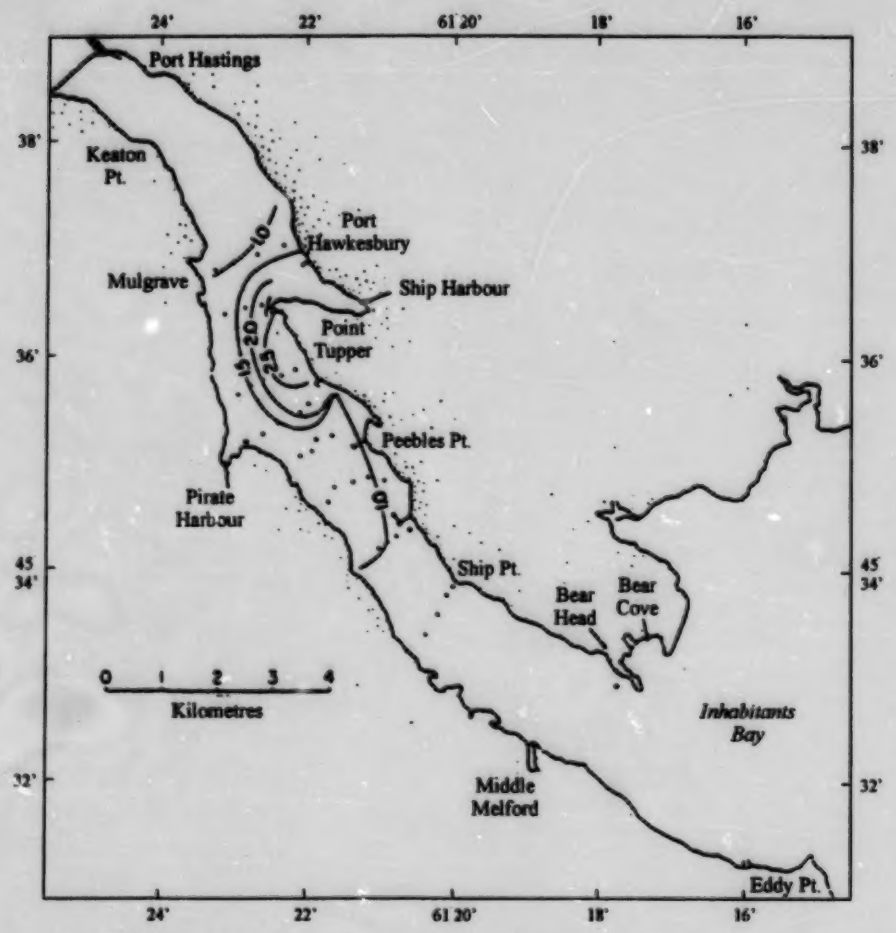


Figure 3.33. Turbidity of surface waters in the Strait of Canso as measured by absolute attenuance of white light (from Buckley *et al.* 1974).

Sediments in Canso Strait have a mixed character, displaying characteristics typical of conditions before the Canso Causeway was constructed, as well as features resulting from the oceanographic environment which prevailed after. In shallower areas near the causeway and in nearshore environments, sediments are coarser-grained gravels and sands with shell debris. Sediments in the vicinity of the pulp mill characteristically have high proportions of wood fibre, and are black and anoxic, giving off a strong odour of hydrogen sulphide (Buckley *et al.* 1974). In deeper waters of the Strait of Canso, the main impact of Causeway construction was to induce the deposition (both north and south of the Canso Strait) of a layer of 2-10 cm of fine deposits (clay, silt and sand) (Buckley *et al.* 1974). Derived mainly from local erosion, this material extends through much of the Canso Strait and into a small area of the inner reaches of Chedabucto Bay.

Sediments in Chedabucto Bay have been largely unaffected by the changes which occurred in Canso Strait. The seabed in nearshore portions of Chedabucto Bay reflects the geological character of the coastline, which may show rocky areas and areas of coarse deposits, while in

deep areas, clay bottom predominates and glacial drift (a mixed sediment type containing a range of particle sizes from clay to rock) occurs in patches. Sand and gravel deposits also occur, particularly southeast of Isle Madame and in the southern approaches of Chedabucto Bay (Buckley *et al.* 1974).

3.5.2 Biology

The prevalence of rocky seabed in the nearshore zone of Canso Strait and Chedabucto Bay, and the predominant influence of Atlantic Ocean favours the development of a seaweed and animal community typical of rocky coastlines over much of the rest of the Atlantic Coast of Nova Scotia (Moore *et al.* 1986). Zooplankton and phytoplankton are also typical of coastal waters in the region, and the local ecosystem likewise includes fish and other vertebrates including seabirds, waterfowl, and marine mammals found elsewhere along the Nova Scotia Atlantic coast (see Table 3.3).

Zooplankton and phytoplankton populations of Canso Strait have rarely been studied although they are expected to be comparable to those in the adjacent waters of the Atlantic Ocean (Table 3.3). The dominant copepod in late winter zooplankton in Chedabucto Bay is *Temora longicaudata* (Conover 1971).

Seabed communities vary in composition depending on the type of bottom and depth, and contain many species typical of other coastal areas along the Atlantic Coast (Table 3.3). Intertidal and shallow subtidal communities along rocky shores in Chedabucto Bay and Canso Strait include:

- *seaweeds*—rockweeds (*Fucus vesiculosus*, *F. spiralis*, *F. serratus*, and *Ascophyllum nodosum*), filamentous green algae (*Cladophora* sp), and Irish Moss (*Chondrus crispus*);

- *invertebrate animals*—hydroids (*Sertularia pumilla*), barnacles (*Balanus balanoides*), snails (including periwinkles, *Littorina littorea*, *L. obtusata* and *L. saxatilis*, and the whelk *Thais lapillus*), limpets (*Acmaea testudinalis*), mussels (*Mytilus edulis* and *Modiolus modiolus*), echinoderms (including the common seastar *Asterias vulgaris* and sea urchins *Strongylocentrotus droebachiensis*), rock crab (*Cancer irroratus*), toad crab (*Hyas araneus*) and hermit crabs (*Eupagurus* sp); and

- *fish*—radiated shanny (*Ulvaria subbifurcata*), shorthorn sculpin (*Myoxocephalus scorpius*), seasnail (*Liparis atlanticus*) and rock gunnel (*Pholis gunnelis*) (Thomas 1973, 1978; Scarratt and Zitko 1972).

On finer intertidal bottoms, communities include animals such as soft-shell clam (*Mya arenaria*); and plant species including cord grass (*Spartina alterniflora*), eelgrass (*Zostera marina*) and *Cladophora* sp (Thomas 1973, 1978).

In uncontaminated areas of the nearshore subtidal zone (chiefly on the western shore of Canso Strait and in Chedabucto Bay), biological communities include:

- *seaweeds*—kelp (*Laminaria* spp, *Agarum cribrosum*), red seaweeds (*Phyllophora truncata*, *P. pseudoceranoides*, and dulse *Palmaria palmata*), and coralline algae (*Lithothamnium* sp and occasionally *Corallina officinalis*);

- *invertebrates*—sea scallop (*Placopecten magellanicus*), horse mussel (*Modiolus modiolus*), slipper shell (*Crepidula fornicata*); mud snail (*Nassarius trivittatus*) and periwinkle (*Littorina littorea*); crabs (rock crab, green crab (*Carcinus maenas*), and hermit crabs); sand shrimp (*Crangon septemspinosa*) and mysid shrimp (*Mysis relicta*); scale worms; sea anemones (*Metridium senile*); bryozoans; sponges (*Halichondria panicea*); and seastars *Asterias rubens* and *Henricia sanguinolenta* (Scarratt and Associates 1994a MS).

Industrial impacts on the Cape Breton shore of Canso Strait have resulted in a reduction in species abundance and diversity of biological organisms in intertidal and subtidal zones there (Scarratt *et al.* 1994a).

In the deep, central areas of the Canso Strait on fine bottom, the animal community is dominated by polychaete and nemertean worms (Martec Limited 1984) and molluscs are virtually absent in most areas, the result of industrial contamination (see Section 3.5.4) (Martec Limited 1984; Buckley *et al.* 1974). The most abundant group of polychaetes are spionids, of which the dominant species is *Prionospio steenstrupi*, but the community includes *Spiophanes kroyeri*, *Spio filicornis*, and *Prionospio cirrifera.* The community also includes twenty-nine additional polychaetes species, a cumacean (an order of crustaceans which lives at the sediment surface); occasional amphipod species (*Casco bigelowi* and *Anonyx lilljeborgi*) and brittle stars (*Ophiura sarsi*) (Pocklington 1987 MS; Tay 1988 MS; Martec Limited 1984). A large, burrowing shrimp (*Axius serratus*) occurs widely on soft bottoms in Canso Strait. The species is unusual in having deep, tubular burrows (more than 2.5 metres long and 1-3 cm diameter at the surface), and has been suggested to have occupied the Strait since industry rendered the area too polluted for other species (Pemberton *et al.* 1976; Scarratt *et al.* 1994a). Fish species on deep mud bottoms of Canso Strait include: Atlantic cod (*Gadus morhua*), Atlantic tomcod (*Microgadus tomcod*), fourbeard rockling (*Enchelyopus cimbrius*), wrymouth (*Cryptacanthodes maculatus*), snake blenny (*Lumpenus lumpretaeformis*), ocean pout (*Macrozoarces americanus*), Atlantic sea raven (*Hemitripterus americanus*), alligatorfish (*Aspidophoroides monopterygius*), American plaice (*Hippoglossoides platessoides*), yellowtail flounder (*Limanda ferruginea*) and winter flounder (*Pseudopleuronectes americanus*) (Martec Limited 1984).

3.5.3 Fisheries

The Canso Strait/Chedabucto Bay region has supported strong commercial fisheries for both finfish and shellfish (Messieh and Moore 1979). Key species include: Atlantic cod, haddock (*Melanogramus aeglefinus*), pollock (*Pollachius virens*), American plaice, white hake (*Urophycis tenuis*); and Atlantic herring (*Clupea harengus harengus*) (Scott 1979; Ware 1979). Herring and mackerel are also fished for use as bait in other fisheries (e.g. lobster), as they are in other coastal areas of Nova Scotia, and Chedabucto Bay is a major overwintering area for herring from along the Atlantic Coast of Nova Scotia as far as the Bay of Fundy (Sinclair and Iles 1985). Among shellfish, the fishery for lobster (*Homarus americanus*) is currently the most important commercially, taking place on both sides of Canso Strait, up to the Canso Causeway (Prouse

1994) and along the coast within a few kilometres of shore throughout Chedabucto Bay. Other species of current or potential importance occur in the area including sea scallop, rock crab, sea urchins, and soft-shell clams (Stasko 1979). Atlantic salmon (*Salmo salar*) migrate through coastal waters to rivers in the area, and the Salmon River and Inhabitants River which flow into Chedabucto Bay, are major salmon rivers, although populations have declined in recent years.

3.5.4 Anthropogenic Sources of Chemicals

Industrial effluents, sewage, contaminated runoff and releases from marine vessel activity and fish processing, as well as two major oil tanker accidents, have added contaminants of various kinds to Canso Strait and Chedabucto Bay, typically petroleum hydrocarbons, pulp fibre, suspended particulates, trace metals, and various organic contaminants (e.g. PCBs and DDT). The most severely impacted area is Canso Strait south of the Causeway, particularly the heavily industrialized eastern shore of Canso Strait, from Peebles Point to Port Hawkesbury.

Several major industries are located on Canso Strait (Table 3.30), many having established in the area after construction of the Canso Causeway. By the early 1970s, a kraft pulp mill, a 'heavy water' plant; an oil refinery; as well as a thermal electric generating plant, a gypsum trans-shipping facility, and numerous smaller businesses operated in the area. Some of the industries have been displaced or replaced (the heavy water plant has been decommissioned and the refinery no longer operates), while those that remain discharge effluent containing a range of contaminants, usually at regulated levels (Wilson 1979; Day 1979; Scarratt *et al.* 1994a). A common user dumpsite for dredge materials is located in the central Strait in the industrialized area (Tay 1988 MS) (Figure 3.30).

Table 3.30. Industries and point sources of pollutants in the Canso Strait in 1994 (from Scarratt and Associates 1994a).

Industry/Point Source	Location	Activity
Canso Seafoods	Canso	Fish Processing
Stora Forest Industries	Port Hawkesbury	Pulp and Paper
Point Tupper Marine Terminals	Point Tupper	Hydrocarbon Transshipping
Nova Scotia Power Corporation	Point Tupper	Thermal Electric Generation
Sewage Treatment Plants	Mulgrave Port Hastings Port Hawkesbury	Secondary sewage treatment
Construction Aggregates Ltd.	Mulgrave	Crushed Rock Production
Georgia Pacific Ltd.	Point Tupper	Gypsum Trans-shipment
Louisiana Pacific Ltd.	Point Tupper	Wallboard Production
Breton Industrial and Marine	Point Tupper	Ship Conversion and Repair

One of the most significant effluents entering the Canso Strait originates in the kraft pulp and newsprint plant at Point Tupper, which discharges high volumes of water, wood fibre, particulates and dissolved organic carbon. During its early operations, the plant released mercury, dioxins and furans (byproducts of the chlorine bleaching processes). Subsequent industry-wide regulation has led to improvements in the quality of effluent since the 1970s, reducing levels of biological oxygen demand, particulates, mercury, and recently levels of

chlorinated organic contaminants (dioxins and furans). Effluent releases prior to controls, and even to the present, however, have created an impacted zone of seabed consisting mainly of wood fibre that continues to be largely barren and lacking normal biological communities for the area. By the early 1970s, this zone extended roughly from Point Tupper to Peebles Point, a distance of 2.8 km, and reached offshore to depths of more than 20 metres (Scarratt and Associates 1994a). The absence of marine organisms is largely due to low oxygen conditions in the wood fibre and near bottom water, and to a texture which is unsuitable for colonization. Nonetheless, mats of white bacterial growth (*Beggiatoa* sp), characteristic of highly organic, anoxic sediments have developed on the surface of the wood fibre deposits (Scarratt and Associates 1994a). A further seabed zone in which many groups of biological organisms are missing, extends significantly beyond the immediate zone of fibre (Buckley *et al.* 1974) (Figure 3.34). Mill effluents have also affected the intertidal and immediate subtidal environment along the coast, causing plants and animals to be absent from Peebles Point to the pulp mill outfall (Buckley *et al.* 1974; Scarratt and Associates 1994a). The improved quality of effluents from the mill as a result of environmental regulations may be beginning to allow biological communities to re-establish in the area, and some organisms have recently been seen on wood fibre deposits, which were not seen in surveys in the early 1970s (Scarratt and Associates 1994a).

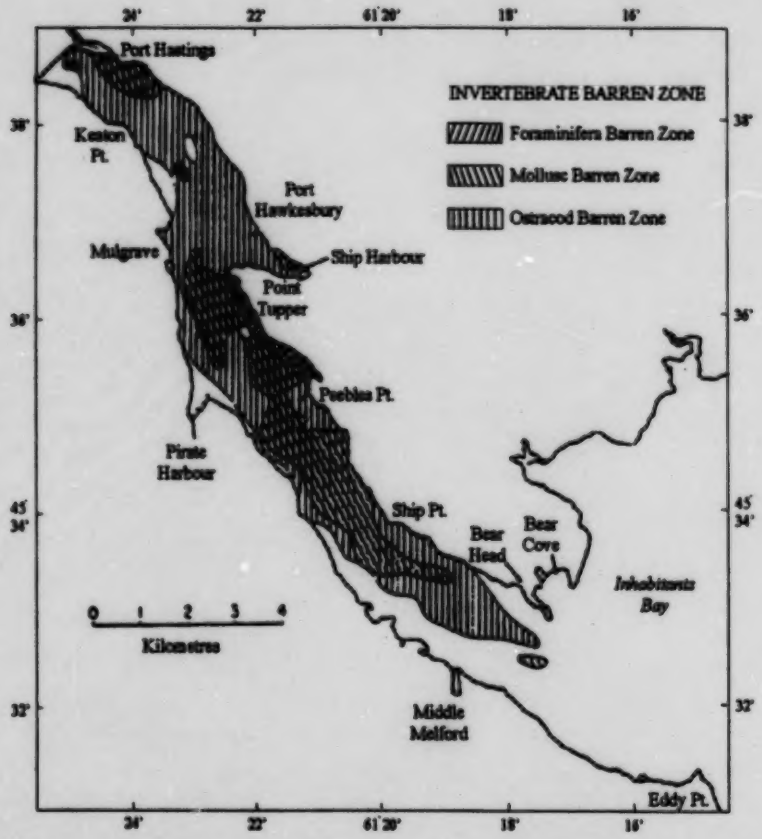


Figure 3.34. Distribution of barren zones for foraminifera, molluscs, and ostracods in the Strait of Canso (from Buckley *et al.* 1974).

Among other industries (Table 3.30), a gypsum trans-shipping facility and associated plasterboard plant in the Port Hawkesbury area, and an aggregate quarry and vessel loading facility on the west side of the Strait at the Causeway, have led to increased turbidity and sedimentation on the seabed in the Strait (Scarratt and Associates 1994a).

In addition to industrial releases, the centres of Port Hawkesbury, Port Hastings, and Mulgrave on the Canso Strait discharge domestic sewage, storm runoff and associated contaminants, including petroleum hydrocarbons and metals into the marine environment. Outside the Strait, fishing and port activities are additional sources of hydrocarbons and metals, as well as organic contamination from fish wastes. Fish plant wastes have been suggested to be the source of elevated concentrations of PCBs in harbour sediments in various ports on Chedabucto Bay. Concentrations found in sediments near the fish plant in Petit-de-Grat Harbour in the early 1980s were among the highest reported on the Nova Scotia Atlantic coast, although recent measurements are not available for comparison (Wiltshire 1978; Ernst *et al.* 1982) (See also Sections 1.3 & 3.2). Elevated concentrations of PCBs in sediments at Canso, on the south coast of Chedabucto Bay, may also be linked to wastes from the local fish plant, in 1979 one of the largest in Nova Scotia (Wilson 1979).

Major Oil Spills and Chedabucto Bay

On 4 February 1970, the oil tanker *Arrow* ran aground on Cerberus Rock in northern Chedabucto Bay, spilling approximately 11.4 million litres (72 000 bbl) of Bunker C fuel oil before its subsequent breakup and sinking on 8 February. Most of the oil was released during the first 24 hours but smaller amounts continued to leak from sunken sections until late March, when cargo salvage operations were concluded. The oil was stranded over an estimated 305 km of the roughly 600 km of shoreline in the Chedabucto Bay area. Less than 50 km of shoreline was treated during subsequent response operations. In addition to contaminating a significant amount of shoreline, and leading to elevated water column hydrocarbon concentrations, large numbers of birds were killed or contaminated (Eaton *et al.* 1986; Owens *et al.* 1994). The *Arrow* spill and subsequent studies led to a significant understanding of impacts of hydrocarbon spills on Atlantic marine coastlines of Nova Scotia. Nonetheless, although most coastlines have been cleansed in the intervening years, significant amounts of oil can still be found in coastal intertidal sediments, in some cases in near unweathered state, now more than a quarter century after it was spilled (Owens *et al.* 1994).

The shorelines of Chedabucto Bay again became contaminated with oil, though to a lesser extent, as the result of a spill of approximately 8.6 million litres (54,300 bbl) of Bunker C oil in the Cabot Strait. On 15 March 1979, the *Kurdistan* en route from Cape Breton to Sept Iles, Quebec, broke apart after encountering pack ice. Oil from the spill spread subsequently along the eastern coast of Nova Scotia including Chedabucto Bay, where sections of the northeast and eastern shorelines had been contaminated by April 19-20. Cleanups undertaken where the oil washed ashore, plus natural weathering of the much reduced volumes spilled, removed much of the *Kurdistan* oil, leaving little to be found to the present day (Vandermeulen 1980; Owens *et al.* 1994).

Marine traffic and related spills and releases, can also contribute to contaminant loads in the area. A spill in 1970 of 11.4 million litres of Bunker C crude oil in northern Chedabucto Bay from the tanker *Arrow* grounding on Cerberus Rock contaminated inshore and coastal sediments (Buckley *et al.* 1974; Keizer *et al.* 1978a), and left oil which in many areas continues to contaminate sediments (Owens *et al.* 1994). A similar but much smaller spill north of Cape Breton Island in 1979 (*Kurdistan*) also brought some oil to Chedabucto Bay. Tanker traffic,

incidental spills, and tank and bilge cleaning is a major source of petroleum contamination of ocean waters worldwide (Wells and Rolston 1991).

3.5.5 Occurrences of Chemicals in Water, Sediments and Biota

The Strait of Canso/Chedabucto Bay system, in addition to having been physically altered by construction of the Canso Causeway, is broadly contaminated with a range of contaminants, including metals and organic compounds (organochlorines, including PCBs and DDT, and petroleum hydrocarbons). The most significant impacts are centred on the Canso Strait, but Chedabucto Bay shows examples of significant sediment contamination in many coastal ports, and some intertidal and subtidal sediments are contaminated by petroleum hydrocarbons from the *Arrow* oil spill, which is an important and unique feature of human impact in this area.

Information on contaminants in the Canso Strait/Chedabucto Bay system, has been derived from a wide range of scientific, and regulatory-related studies of various environmental concerns, including: the impact of Canso Causeway construction on the marine environment (Buckley *et al.* 1974; McCracken 1979); impacts of contamination from industries in the Port Hawkesbury area (Wilson 1979; Day 1979); effects of major oil spills and extent of petroleum hydrocarbon contamination (Vandermeulen 1980; Levy *et al.* 1988; Owens *et al.* 1994); background studies for the selection of the site and subsequent monitoring of a 'common user' ocean dump site in the Strait (Martec Limited 1984; OceanChem 1987; Tay 1988 MS); and sampling required for ocean dumping approvals of coastal dredging and construction projects (OceanChem 1985), as well as many other studies.

Water

Contaminant concentrations in the waters of Canso Strait have not been measured since the early seventies. At the time, levels of metals in surface waters were higher than in the deeper waters, and decreased with distance from the industrialized area (Peebles Point to Port Hawkesbury), reflecting local input of industrial and domestic effluents (Tables 3.31 & 3.32) (Buckley *et al.* 1974). Only mercury, at concentrations 0.04 to 0.44 µg/L, reached levels above the 0.1 µg/L guideline for protection of marine life (McNeely *et al.* 1979) (Cranston *et al.* 1974). In the early 1980s, Canso Strait waters at Port Hawkesbury had low concentrations of PAHs, (less than 0.01 µg/L) (O'Neill and Kieley 1992; Environment Canada 1995MS), below levels of concern and within the range of several coastal harbours (excluding Sydney Harbour) for which such analyses have been conducted.

Table 3.31. Dissolved metal concentrations in seawater in Canso Strait south of Canso Causeway. Surface water, less than 15m; bottom water, >15m (from Buckley *et al.* 1974).

Metal	Area								
	Concentration (ug/L)								
	Average		North of Point Tupper (Inner Strait)		Industrial Area (Middle Strait)		South of Peebles Point (Outer Strait)		Nova Scotia Shelf (Buckley *et al.* 1974).
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	
Iron	8	2	7	6	22	4	11	4	7
Manganese	135	165	151	60	240	69	76	50	26
Zinc	15	6	12	5	17	5	6	4	8

Table 3.32. Distribution of dissolved metal concentrations in seawater in Canso Strait with distance from the industrialized area (from Buckley *et al.* 1974).

Distance from Pulp Mill (km)	Concentration (ug/L)						
	Cadmium	Copper	Iron	Lead	Manganese	Nickel	Zinc
0 - 0.5 km	0.016	0.35	3.9	0.42	28.0	0.65	3.13
0.5 - 1.0 km	0.015	0.18	1.5	0.23	18.9	0.60	1.03
1.0 - 3.0 km	0.019	0.20	1.3	0.40	15.4	0.53	0.81
> 3 km (background)	0.017	0.34	0.5	0.21	7.5	0.36	0.90

Sediments

Sediments in the Canso Strait/Chedabucto Bay system have been shown to contain significantly elevated levels of various contaminants, including metals, PAHs and PCBs. Most contamination is centred in the industrial region of the Canso Strait, roughly from the oil refinery seaward of Peebles Point to Mulgrave, particularly nearshore and adjacent to wharves and outfalls. Although much of the contamination is localized, surficial sediments throughout the central Strait have elevated metals and PCBs. Additional localized contamination occurs in and around fishing wharves and fish plants, and, owing to the *Arrow* tanker spill in 1970, petroleum hydrocarbon contamination occurs in some shoreline and subtidal sediments.

In the early 1970s, concentrations of lead, mercury, copper and zinc in Strait of Canso sediments were higher than background and for adjacent areas of Chedabucto Bay (Table 3.33) (Buckley *et al.* 1974) (Figure 3.35). Elevated mercury concentrations occurred within 0.5 km of the coast

near the pulp mill (Table 3.33), attributed to mercury in effluents from that facility. Mercury concentrations in sediments, measured subsequently, are lower, attributed to the elimination of releases of mercury from the pulp and paper production process at Point Tupper. A 1987 survey indicated that mercury content of sediments in the central Strait was less than 0.2 μg/g (OceanChem 1987) and thus below background levels for sediments in coastal inlets on the Atlantic coast (Loring *et al.* 1996).

Table 3.33. Metal and contaminant concentrations in sediments in Canso Strait and Chedabucto Bay.

	Area and Date										
	Concentration (ug/g dry weight)										
	Canso Strait (Inner, Middle, and Outer–Causeway to Bear Head) 1973 (1)	North of Point Tupper (Inner Strait)		Industrial Area (Middle Strait–Point Tupper to Pebbles Point)			South of Pebbles Point (Outer Strait)	Chedabucto Bay			
		1973 (2)	1983 (4) (66 - 78 m)	1973 (2)	1983 (4) (60 - 63.5 m)	1987 (3)	1983 (4) (61 - 65.6 m)	Canso Strait mouth (Eddy Point to Bear Head) 1973 (2)	Isnvim Island 1973 (2)	Inhabitants Bay 1973 (2)	Outer Approaches (180 m) 1983 (4)
Metals											
Copper	4.1 - 13.4	25 - 53 (avg 37.3)	32 - 54 (avg. 40)	10 - 37 (avg 25.2)	30 - 44 (avg. 37)	14.2 - 56.6 (avg 29.3)	29 - 32 (avg. 30)	14 - 29 (avg 18.2)	7 - 25.0 (avg 18.4)	10 - 38 (avg 23.4)	23 - 30 (avg. 27)
Cadmium			0.51 - 0.79 (avg. 0.64)		0.20 - 0.68 (avg. 0.45)	0.2 - 0.7 (avg. 29.3)	<0.10 - 0.48 (avg. 0.30)				< 0.10 (avg. <0.10)
Iron	10,000-17,000	——NO DATA——									
Lead	7.7 - 16.1	25 - 75 (avg 41.7)	48 - 51 (avg. 50)	25 - 120 (avg 62.5)	44 - 45 (avg. 45)	23.9 - 51.5 (avg 40.4)	41 - 43 (avg. 42)	50 - 120 (avg 72.1)	50-100.0 (avg 63.4)	25 - 110 (avg 57.5)	28 - 34 (avg 32)
Mercury	0.011 - 0.148	0.21-0.44 (avg 0.34)	0.03 - 0.05 (avg. 0.04)	0.22 - 3.7 (avg 2.16)	0.03 - 0.05 (avg. 0.04)	< 0.2	0.02 - 0.03 (avg. 0.03)	0.44 - 3.1 (avg 1.5)	0.35-0.83 (avg 0.62)	0.18 - 1.0 (avg 0.95)	0.01 (avg. 0.01)
Zinc	14.8 - 80.9	80 - 122 (avg. 105.8)	122 - 128 (avg. 125)	63 - 250 (avg 93.2)	114 - 122 (avg. 116)	80.0 - 153.0 (avg 127.2)	100 - 108 (avg. 105)	38 - 100 (avg 72.6)	60-130.0 (avg 75.5)	50 - 93 (avg 72.1)	75 - 80 (avg. 77)
Pesticides											
op DDE (ng/g)			16 - 23 (avg. 19)		15 - 25 (avg 20)		8 - 16 (avg. 13)				1.0 (avg. 1.0)
pp DDE (ng/g)			3 - 7 (avg. 6)		5 - 8 (avg. 7)		2 - 8 (avg. 5)				3 - 8 (avg. 5)
pp DDT (ng/g)			11 - 20 (avg. 17)		21 - 25 (avg. 23)		13 - 23 (avg. 19)				7 - 17 (avg. 11)
Total DDT (ng/g)			42		50	less than 0.2	37				17
PCBs											
Aroclor 1254 equivalents (ng/g)			60 - 76 (avg 69)		76 - 86 (avg. 80)	48 - 1,395 (avg. 329)	48 - 84 (avg. 73)				2 - 4 (avg. 3)

SOURCES: 1. Wilson (1979); 2. Cranston *et al.* (1974) summarized in OceanChem (1985); 3. OceanChem Group Limited (1987); 4. Maritec Limited (1984).

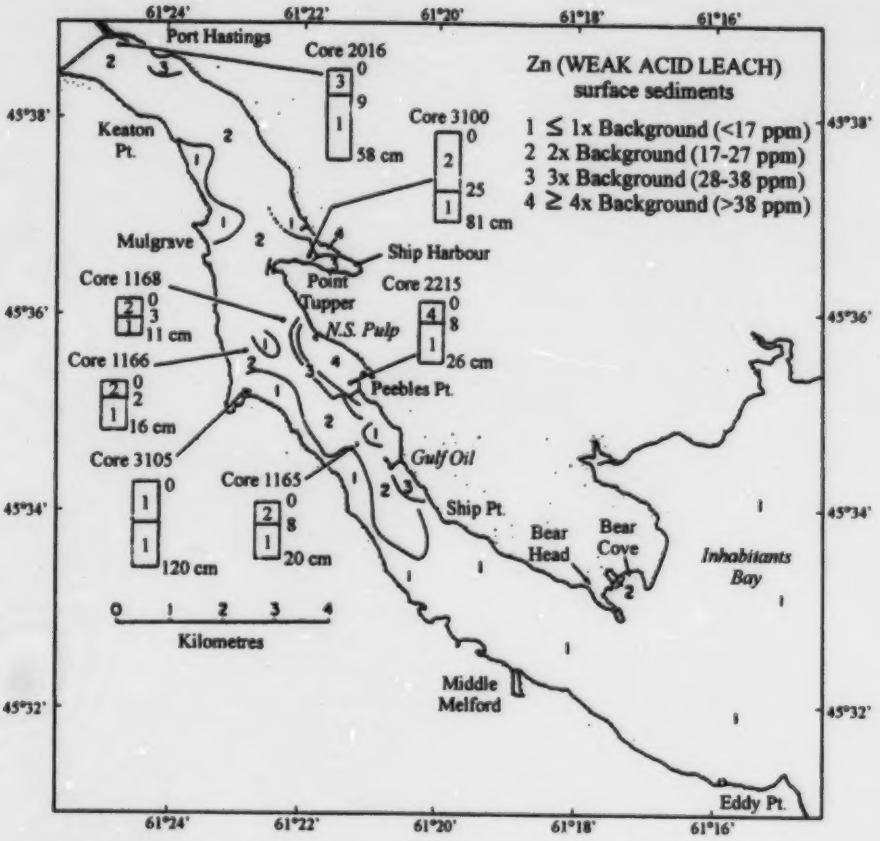


Figure 3.35. Distribution of leachable (weak acid) zinc in surface sediments in the Strait of Canso. Higher levels indicate more recent contamination (from Buckley *et al.* 1974).

Levels of other metals (copper, lead and zinc) in Strait of Canso sediments in the late 1980s were similar to those in the early 1970s (Table 3.33), and highest levels are comparable with background concentrations for Nova Scotian Atlantic coastal inlets (Loring *et al.* 1996). Concentrations of cadmium in sediments in the industrialized portion of Canso Strait in 1987, were comparable to those observed in a 1983 study (OceanChem 1987, Table 3.33).

Elevated cadmium concentration has been a feature of nearshore sediment contamination in the Strait of Canso since the early 1970s. Cadmium concentrations measured for ocean dumping purposes at Port Hawkesbury in the late 1970s (ranging from 0.2 - 3.1 μg/g) were above the allowable concentration for ocean dumping (0.6 μg/g) (Baker and Matheson 1980). Levels in the industrialized area of central Canso Strait are also elevated, in 1987 frequently exceeding the Canadian guidelines for ocean disposal (OceanChem 1987) as well as background concentrations for Atlantic coastal sediments.

PAH concentrations have been measured only occasionally in sediments from coastal areas in Canso Strait/Chedabucto Bay. In Ship Harbour (Port Hawkesbury), PAH levels range from low

to moderate (39 - 2,940 ng/g dry weight) (O'Neill and Kieley 1992). Concentrations of PAHs above 2,500 ng/g dry weight typically require additional screening prior to ocean dumping. In Chedabucto Bay, low concentrations of PAHs have been found in sediments from L'Ardoise harbour (34 ng/g dry weight), and high levels at Canso (3,670 ng/g) (OceanChem 1985). These concentrations are significantly above levels in uncontaminated coastal sediments which typically reach 500 ng/g (Hildebrand 1984). The most likely source of the elevated levels of PAHs at these sites is creosote from wharf pilings.

Elevated PCB concentrations have been a widespread occurrence in sediments of the industrialized part of central Canso Strait. Concentrations ranged from 48 to 1,395 ng/g (average 329 ng/g) at 17 stations spread uniformly across and along the Strait between the thermal generating facility at Point Tupper and Mulgrave, with highest values occurring closest to the northern industrialized shore (Table 3.33) (OceanChem 1987). An extreme level of 2,630 ng/g has been measured in sediments at the common user ocean dumpsite in the area (Figure 3.30) (OceanChem 1987). Elevated levels of PCBs have also been reported for harbour sediments from Mulgrave (up to 417 ng/g), although only moderate levels have been found at Port Hawkesbury (up to 76 ng/g) (OceanChem 1985), and at several prospective dumpsite locations in deep basins in the Strait in 1983 (from 76 to 86 ng/g) (Martec Limited 1984). Such levels are above measured background in Chedabucto Bay (Table 3.33) and for the Atlantic Coast near Halifax (5 ng/g) (Leonard 1977), and are typically above the interim Canadian sediment quality guideline for PCBs of 21.5 ng/g (Environment Canada 1995). No explanation for the widespread occurrence of PCBs in sediments in the Central Canso Strait has been proposed, although it would appear that the contamination is associated with industrial development there.

Outside Canso Strait, elevated PCB concentrations in sediments have been found near fish plants in several ports surrounding Chedabucto Bay. In the mid-1970s, elevated levels of PCBs were detected in sediments (Petit-de-Grat Harbour, 138.4 ng/g; West Arichat, 37.5 ng/g; and l'Ardoise, 12.5 ng/g) (Travers and Wilson 1977), while a subsequent, in-depth study of Petit-de-Grat Harbour, found much higher concentrations (up to 20,000 ng/g dry weight) adjacent to the main fish processing and meal plant, and decreasing away from the plant (Ernst *et al.* 1982). No PCB sources were associated with the plant equipment and facilities, and the compounds were believed to have originated in lipids from fish waste, but a conclusive link has not been shown (Zitko, Fisheries and Oceans Canada, personal communication; Wells and Rolston 1991). Fish plant waste may also be responsible for elevated concentrations of PCBs (up to 27,500 ng/g) in sediments near wharves at Canso (OceanChem 1985).

In addition to these contaminants, low concentrations of dioxins and furans have occurred in sediments in the vicinity of the pulp mill at Point Tupper (Trudel 1991); and concentrations of the anti-foulant and preservative chemical tri-n-butyltin have been detected in Port Hawkesbury sediments (Maguire *et al.* 1986). DDT concentrations in Central Canso Strait sediments in 1983 were significantly higher than background levels from Chedabucto Bay (Table 3.33) (Martec Limited 1984), having levels (including background) typically well above the interim Canadian sediment quality guideline for DDT and its congeners (Environment Canada 1995), indicating that the compounds were still widely distributed in the marine environment even after a decade during which they were not released to the environment. Lower, and more acceptable, levels of

total DDT (less than 5 ng/g) have been detected in Port Hawkesbury and Mulgrave harbour sediments (OceanChem 1985).

Sediments in the Canso Strait/Chedabucto Bay system may also contain elevated levels of petroleum hydrocarbons from industrial effluents, operational releases from ships and fishing vessels, or from accidental releases, such as the oil spilled from the tanker *Arrow* in 1970. At Point Tupper, petroleum hydrocarbon concentrations in sediments are among the highest in Nova Scotia, ranging from 6.0 to 247.0 μg/g (average 52.6), and at Port Hawkesbury from 7.1 to 77.5 (average 33.8) (Levy *et al.* 1988) (Figure 3.6), although concentrations as high as 4,160 μg/g have been measured there (OceanChem 1985). The highest values are comparable to the most contaminated sediments in Atlantic Canada, while average concentrations are about half the levels in contaminated Halifax Inlet sediments, and above the 10 μg/g or less found in the majority of harbours in Atlantic Canada. 10 μg/g was used formerly as a guideline for oil and grease content for disposal at sea under the Canadian Environmental Protection Act.

The *Arrow* spill added petroleum hydrocarbons chiefly to intertidal sediments in Chedabucto Bay. Within three years of the 1970 spill, one site on the northern coast of Chedabucto Bay had concentrations in intertidal sediments ranging from 7 to 1280 μg/g oil depending on depth, tide level and type of bottom (Keizer *et al.* 1978a). Subtidal sediments, however, showed little influence of petroleum hydrocarbons from the oil spill, although concentrations in some areas were slightly elevated over sediments from the outer approaches of Chedabucto Bay. Typical levels, measured as solvent-extractable organic matter (which overestimates hydrocarbon concentrations—petroleum hydrocarbon content may be from 50 to 75% of these values) ranged from 5 to 2092 μg/g dry weight (Keizer *et al.* 1978a). The highest concentrations occurred in finer sediments, particularly near population centres. In 1992, oil from the *Arrow* spill was still visible in the intertidal and upper shore zone on about 5% of the Chedabucto Bay shoreline, and measurements of petroleum hydrocarbon composition indicated that in some cases the oil was virtually unweathered (Owens *et al.* 1994).

Biota

Lobster—Levels of several contaminants in lobster from the Canso Strait/Chedabucto Bay area do not appear to be significantly elevated compared with other Nova Scotia coastal areas. In 1973, cadmium concentrations of 7.9 μg/g wet weight (range 3.22 - 19.6) were measured in digestive glands of lobster (1973) in Arichat (Uthe and Freeman 1980). These levels were slightly below averages for lobster from throughout the Atlantic region (average, 8.9 μg/g, range 1.0 - 79.1 μg/g) (Uthe and Freeman 1980) and far below levels in a cadmium-contaminated area of New Brunswick (Uthe and Freeman 1980).

A wide range of PAH concentrations, including some relatively high values, have been found in the digestive glands of lobster from oiled areas of the Cape Breton coast including Chedabucto Bay after the *Kurdistan* spill. Levels ranged from a maximum in Petit-de-Grat Harbour of 5,655 ng/g pyrene equivalents) (Scarratt 1980) and in western Chedabucto Bay (3,636 ng/g wet weight) (Sirota and Uthe 1980), compared with levels of 241 to 2,412 ng/g pyrene equivalents (a measure of PAHs reflecting the type of analytical method) in other coastal areas exposed to oiling. PAH concentrations in lobster digestive gland are typically highly variable (Sirota and

Uthe 1980), and a connection between PAH concentration and oil contamination was not established in these studies; PAHs may have reached lobsters from other sources, such as through exposure to sediments and waters contaminated with creosote from wharves.

Following the *Kurdistan* spill in 1979, concentrations of petroleum hydrocarbons in lobster from coastal areas in Chedabucto Bay were elevated compared with control sites, but were not as high as levels for lobster from a heavily industrialized area (Halifax Inlet) (Scarratt 1980). Nonetheless, concentrations of petroleum hydrocarbons in lobster digestive gland in oiled areas were relatively low, ranging from 180 to 640 ng/g wet weight versus 110 ng/g for "clean" areas and 1,630 ng/g for Halifax area lobster (Scarratt 1980). No other estimates of background hydrocarbon concentration in lobster are available.

Mussels—In general, levels of trace metals in mussels in Canso Strait and Chedabucto Bay are elevated over background concentrations, though comparable to other areas of Nova Scotia and North America where coastal contamination occurs. In 1980, blue mussels from the Strait of Canso had tissue zinc concentrations in the range of 100-150 μg/g dry weight (Cossa (1980) from Messieh and El-Sabh 1988), comparable to averages from U.S. Mussel Watch sites (O'Connor 1992). With adjustment for wet weight/dry weight differences, these zinc levels appear to be comparable to levels measured by Environment Canada at several other contaminated coastal sites in Nova Scotia, though above levels at an uncontaminated coastal site (Beaver Harbour) (Tables 3.5, 3.14, 3.28 and 3.29) (Zenon Environmental Inc, 1989MS).

PAH concentrations in blue mussel (*Mytilus edulis*) for Chedabucto Bay (Janvirn Harbour, Petit-de-Grat Harbour and Lennox Passage) were shown to be higher than control areas after the *Kurdistan* spill, with concentrations ranging from 51 to 1093 ng/g pyrene equivalents, versus levels of 6 to 77 ng/g for controls (Larry's River and Havre Boucher) (Scarratt 1980), and were elevated, in some cases significantly, over present-day values from mussels from U.S. coastal areas (Table 1.4) (O'Connor 1992). These levels were also above levels in mussels from several sites on the Atlantic Coast of Nova Scotia, in which levels of key PAH compounds in 1989 were not detected at levels below 100 μg/g wet weight (Tables 3.5, 3.14, 3.28 and 3.29) (Zenon Environmental Inc, 1898MS). No recent measurements from those sites have been made to determine whether levels in mussels have changed in recent years.

Concentrations of most contaminants in mussels sampled in Canso in 1989 (Table 3.29), were comparable to those at an undeveloped coastal site (Beaver Harbour), although lead was elevated, while cadmium concentration was lower (Table 3.5) (Zenon Environmental Inc. 1989MS). Lead levels were comparable to those found in mussels from some of the other industrialized inlets, while lead, chromium and mercury (allowing for wet weight/dry weight differences in measurements) were higher than U.S. Mussel Watch sites (O'Connor 1992) (Table 1.4). Levels of di-*n*-octyl phthalate were comparable to other Nova Scotia sites.

Other Organisms—In the early 1980s, benthic fauna near a fish plant at Petit-de-Grat Harbour (worms (*Nereis* sp), clams (*Mya* sp), and periwinkles (*Littorina littorea*)) had elevated levels of PCBs, compared with those from a coastal area having no fish plants or other industrial pollution sources (Ernst *et al.* 1982, Table 3.34), but local pollock (*Pollachius virens*) had muscle concentrations from below to slightly above levels from fish caught offshore—much lower than

other fish species from parts of the world where known elevated concentrations of PCBs had occurred (Ernst *et al.* 1982; OceanChem 1985).

Table 3.34. Concentrations of PCBs in marine organisms from Petit-de-Grat harbour near the Richmond Fisheries Wharf, 1981 (from OceanChem 1985).

Organism	Tissue	PCB Concentration (ug/g wet weight)	
		Petit-de-Grat Harbour	Uncontaminated Areas
OceanChem (1985)			
Rock crab (*Cancer irroratus*)	Whole Animal	0.5 - 1.9	–
Starfish (*Asterias forbesii*)	Whole Animal	0.02 - 0.05	–
Winter flounder (*Pseudopleuronectes americanus*)	Liver	0.17 - 6.4	–
	Gonad	0.07 - 0.56	–
	Muscle	0.005 - 0.24	–
Pollock (*Pollachius virens*)	Liver	1.1 - 7.0	–
	Gonad	0.5 - 6.7	–
	Muscle	0.002 - 0.005	–
Sculpin (*Myoxocephalus aemeus*)	Liver	29	–
	Muscle	2	–
Ernst *et al.* (1982)			
Pollock (*Pollachius virens*)	Liver	0.170	–
	Muscle	< 0.010	0.01 [1]
Polychaete (*Nereis* sp.)	Whole Animal	0.054 - 0.060	(< 0.010) [2]
Softshell clam (*Mya* sp)	Tissue	0.028 - 0.036	(< 0.010) [2]
Periwinkles (*Littorina littorea*)	Tissue	0.089 - 0.140	(0.020) [2]
Plansearch (1981) (from Ernst *et al.* 1982)			
Pollock (*Pollachius virens*)	Liver	3.55 - 14.86	–
	Muscle	0.05 - 0.09	–

1. Scotian Shelf (Sims *et al.* 1977)
2. Control area, Grand Desert Beach, Nova Scotia

Oil contamination in the nearshore environment of Chedabucto Bay from the *Arrow* spill led to elevated concentrations of petroleum hydrocarbons long after the spill in some organisms. In 1975, various organisms were contaminated with petroleum hydrocarbons; softshell clams in an oiled area had petroleum hydrocarbon concentrations of from 12.4 to 14.2 µg/g wet weight, and eelgrass (*Zostera marina*) contained levels of 17.1 µg/g (Vandermeulen and Gordon 1976). In contrast, rockweed (*Fucus* sp) and blue mussels did not show petroleum hydrocarbons in tissues.

The eelgrass and soft shell clams are associated with depositional areas where oil may be expected to accumulate, while rockweed and blue mussels occur on hard substrate and may not be so readily exposed to petroleum hydrocarbons. No more recent measurements are available to determine recovery of biota in the area.

3.5.6 Summary and Conclusions

The Canso Strait marine system is a young one, still in transition, having been significantly modified by a major human intervention within the last four decades—the construction of the Canso Causeway—and by major industrial inputs, from whose impacts it is only now beginning to recover. Elevated concentrations of contaminants occur in localized 'hotspots', such as the deposits of wood fibre found adjacent to a major pulp mill on its shores, and elevated contaminant levels in areas used for ocean disposal, while industrial activity has led to the occurrence of elevated trace metals and suspended particulate matter in surface waters, and widespread distribution in the sediments of contaminants, typically trace metals (including some of particular concern, such as cadmium) and organic contaminants such as PCBs.

Chedabucto Bay, is relatively unaffected by human activities; but nonetheless, significant examples of contamination occur. A major oil spill resulting from the grounding of the tanker *Arrow* subjected the Bay to extensive oiling in 1970 and oil from the *Kurdistan* spill in 1979 also reached it. Impacts from spills remain, mainly in the presence of oil in coastal sediments, although natural processes such as wave action, degradation by light, and mixing with sediments and fine particulate matter, have removed most of the original oil. Only short-term impacts on biological organisms in the area appear to have occurred. Of more concern, coastal marine areas around fishing ports have contamination problems, including elevated levels of petroleum hydrocarbons, PCBs and metals, resulting from local vessel activities, and discharge of fish plant wastes. In particular, the occurrence of high concentrations of PCBs in sediments adjacent to fish plants in some of these locations has been a major environmental concern in the past two decades. PAHs, often from use of creosote-treated wood in wharves occur at elevated concentrations in lobster tissues in some of these areas, reflecting a more general contamination problem for the Atlantic coast. Apart from efforts to address the most significant concerns, little has been done to study contaminant concentrations and distribution in Chedabucto Bay. The overall lack of information is a major data gap for the area.

3.6 SHELBURNE HARBOUR

Oceanography and Biology

Shelburne Harbour and Shelburne Bay occupy a 24-km bifurcating basin on the south coast of Nova Scotia, about 200 km southwest of Halifax (Figure 3.3). The easternmost arm is the entry point for the Roseway River (the main source of freshwater inflow, mean monthly flow of 16 m^3 s^{-1}). The outer bay has two passages (Eastern and Western Ways) exiting on either side of a protecting island (McNutts Island) (Figure 3.36). The system is relatively shallow, reaching 13.1 m in the inner bay and 16.4 m in the outer areas. Tidal ranges and flushing times for the inner and outer bay are 1.7 to 2.4 m, and 52.6 hours and 46.8 hours respectively (Gregory *et al.* 1993)). The seabed consists mainly of sand or cobbles at the approaches, merging into mud bottom further up the estuary, and having boulders and gravel nearshore (Scarratt and Associates 1994b). Sheltered areas may have fine sediments in shallow waters, supporting eelgrass (*Zostera marina*) beds in the subtidal zone and saltmarsh grasses (*Spartina* spp) in the intertidal and higher elevations. At Shelburne, an accumulation of sawdust and wood chips occurs on the estuary bottom.

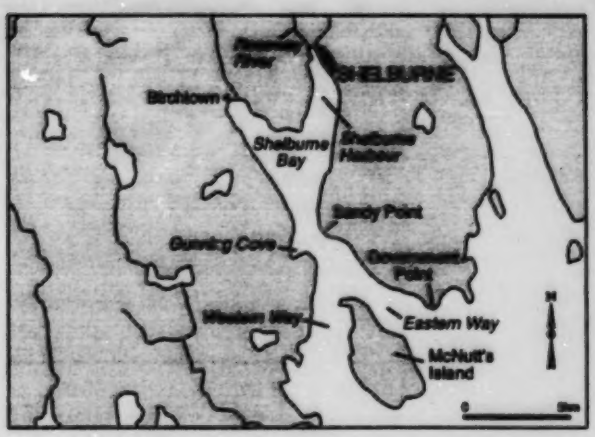


Figure 3.36. Shelburne Harbour and adjacent areas.

The Town of Shelburne, the major population centre in the area (2,245 in 1991), rests at the head of the eastern arm. Industrial development includes shipyards, fish plants, wharves and shipping concerns. The town has a secondary sewage treatment system that discharges chlorinated effluent. Three salmon aquaculture facilities, two on the west and one on the eastern side of the harbour, were operating in 1994 (Scarratt and Associates 1994b). The western side of the harbour is largely pristine, having no industrial development and only a few scattered dwellings.

Neither the town nor the aquaculture operations appear to have caused significant contamination of the harbour (Scarratt and Associates 1994b), although extensive mats of the bacterium *Beggiatoa* sp (which grows in cases of high organic enrichment of the bottom, often caused by human dumping of fish wastes) occur in the vicinity of the Government wharf (Scarratt and Associates 1994b).

An important lobster fishery takes place in Shelburne Harbour, in 1994 occupying 11 boats and resulting in a seasonal catch of 6,400 kg (Prouse 1994). The seabed supports populations of invertebrates having potential commercial importance, including the Ocean quahaug (*Arctica islandica*) (Chandler 1983); and rock and jonah crabs (*Cancer irroratus* and *Cancer borealis*) (Lanteigne (1985) from Scarratt and Associates 1994b).

Chemicals in Water, Sediments and Biota

Information on contaminant concentrations in Shelburne Harbour comes mostly from sediments in shipping channels and vessel berthing areas, sampled to determine their acceptability for dredging and ocean disposal, but a scientific survey of comtaminants in bottom sediments has been carried out by Fisheries and Oceans Canada (Loring *et al.* 1996).

In general, concentrations of metals and organic contaminants in Shelburne Harbour are low, but elevated concentrations of some metals, in particular cadmium, have been observed in some cases. Cadmium concentrations in sediments near the public wharf in Gunning Cove on the western side of the inlet in the early 1980s exceeded the ocean dumping limit (OceanChem 1985) and the highest levels of PCBs measured for ocean dumping purposes in Nova Scotia in the 1970s (278 - 374 ng/g) were also found there (Wilson and Travers 1977).[5] Oil and grease concentrations in some samples in Shelburne Harbour in the early 1980s were also elevated, reaching 2,875 μg/g, well above the ocean dumping limit of 10 μg/g (OceanChem 1985 from Prouse 1994). A recent survey by Loring *et al.* (1996) found high concentrations (above accepted backgrounds) of cadmium (0.02 - 1.32 μg/g) in the harbour as a whole but otherwise levels were below background (levels determined to be representative of uncontaminated sediments) (See Section 3.2, Figure 3.5). Typical concentrations for metals of concern were: copper (2 - 44 μg/g); lead (10 - 80 μg/g); mercury (0.01 - 0.23 μg/g) and zinc (8 - 90 μg/g).

Shelburne was also identified as a site of significant usage of tributyltin (a preservative chemical toxic to marine organisms) in shipbuilding and repair (Kieley 1989) but no measurements in the environment, or assessment of current status of use of the chemical is available.

[5] Areas sampled near wharves and in shipping channels are often subject to contamination by human activities and also most often have finer sediments, which also tend to have elevated concentrations of certain contaminants. Surveys which focus on these areas give an incomplete picture of levels of contamination in the harbours as a whole. This bias applies to most coastal inlets in Nova Scotia except in cases where broader surveys have been conducted.

3.7 LIVERPOOL BAY AND HARBOUR

Oceanography and Biology

Liverpool Bay is a funnel-shaped inlet approximately 6 km long and 2 km wide at its broadest extent, and having at its head the estuary of the Mersey River (Figures 3.3 & 3.37). The Mersey provides a significant freshwater inflow, ranking highest among Nova Scotia Atlantic rivers (mean discharge of 57 $m^3 s^{-1}$). Depths in the estuary increase from about 4 metres at the river mouth to about 23 metres at the seaward end. The Bay has a moderate tidal range of 1.6 to 2.2 m and a flushing time of 65.0 hours (Gregory *et al.* 1993).

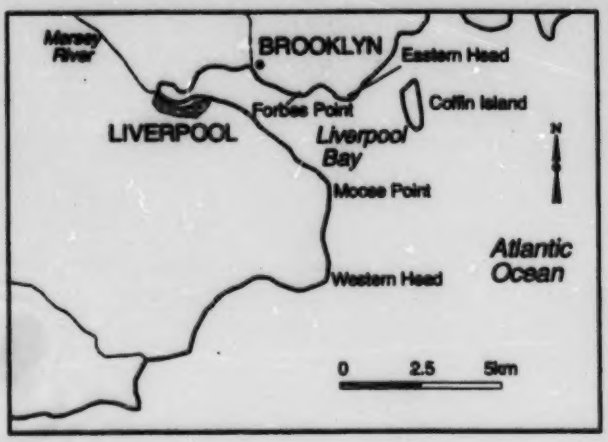


Figure 3.37. Liverpool Bay and Harbour

Shores of Liverpool Bay are mainly rocky or dominated by boulder substrate, and approaches (where wave exposure is greatest) consist predominantly of sands, with areas of sandy gravel to gravel and coarser (including boulder) bottoms in the outer areas (Piper *et al.* 1986). Inner portions of Liverpool Harbour have muddy bottoms, or silt containing significant proportions of sand and clay, but clay predominates in areas adjacent to wharves (OceanChem 1985). Wood fibre is a predominant deposit around the pulp mill in Brooklyn (particularly in Herring Cove on which the mill is situated).

There have been few studies of the biology of Liverpool Bay but a recent survey by Scarratt and Associates (1994b) indicated an abundant and diverse community of marine organisms. A lobster fishery takes place in the outer part of Liverpool Bay and approaches (Prouse 1994).

The Town of Liverpool is situated at the mouth of the Mersey River and is an industrial center (population 3,115, 1991). The site is a major berthing area for fishing vessels (52 registered, 3,371 tonnes), and supports 13 manufacturing and processing firms, including several fish processing plants, local manufacturing industries and a small shipyard (Prouse 1994; Scarratt and Associates 1994b). The Bowater-Mersey Pulp and Paper Mill is located across Liverpool Bay in Brooklyn (population 1,253, 1991).

Chemicals in Water, Sediments and Biota

There is little recent information on contaminant concentrations in Liverpool Bay and Harbour, but in general, concentrations of petroleum hydrocarbons, metals and some organic contaminants in sediments are above accepted backgrounds for uncontaminated coastal inlets. Petroleum hydrocarbon concentrations in sediments in the late 1970s-early 1980s have ranged from low to high in the inner harbour (localized concentrations up to 6,100 $\mu g/g$, measured as total oil and grease) (OceanChem 1985; Levy *et al.* 1988). On average, however, sediments adjacent to the

Town of Liverpool and in wharf areas in the Brooklyn area in the late 1970s were only slightly above averages for a range of small Atlantic region ports having little industrial activity and population development. Concentrations in Liverpool Harbour averaged 15.1 μg/g (3.0 to 61.5 μg/g) compared with an average of 10 μg/g for the other ports (Levy *et al.* 1988).

Concentrations of PCBs and PAHs elevated above background have been found in sediments in Liverpool Harbour in the inner harbour channels and berthing areas requiring dredging (Travers and Wilson 1977; OceanChem 1985) (see Section 1.3 for a discussion of background levels). Levels of PCBs were occasionally above the permissible limit for ocean disposal (Table 3.35), while PAH concentrations in sediments (0.4 - 11.8 μg/g) (from OceanChem 1985; Environment Canada unpublished ocean dumping data in Prouse 1994) are within the range observed in other Nova Scotia Atlantic ports (range, 0.02 to 87 μg/g) (OceanChem 1985).

Table 3.35. Concentrations of key contaminants in sediments from Liverpool Bay and Mersey River estuary (from OceanChem 1985).

	Concentration (ug/g dry weight)	
	Liverpool Area	Brooklyn Area
Metals		
Cadmium	< 0.2 - 0.52 (avg. 0.37)	0.10 - 1.64 (avg. 0.77)
Copper	–	3.11 - 30.3 (avg. 15.8)
Mercury	< .05 - 0.88 (avg. 0.15)	< 0.1
Lead	< 6 - 10 (avg. 4.3)	2.5 - 23.8 (avg. 18.6)
Zinc	10 - 104 (avg. 45.05)	17 - 85 (avg. 56.3)
Chlorinated Organics		
PCB (Total)	30 - 1,400 (avg. 109.6)	< 5 - 44.4 (avg. 22.0)
DDT (Total)	< 0.00007 - 0.134 (avg. 0.0239)	< 0.005

Localized occurrences of elevated cadmium and mercury were found in some sediments in Liverpool Harbour in the early 1980s, above the limit for ocean disposal for cadmium and near the limit for mercury (OceanChem 1985). Although hotspots may still occur, sediments in the Harbour are presently not significantly elevated with the exception of cadmium. Loring *et al.* (1996) found concentrations of most metals (except for cadmium) at or below background: cadmium (0.02 - 0.90 μg/g) (versus background of 0.3 μg/g, See Table 1.3); copper (2 - 16 μg/g); lead (12 - 21 μg/g); mercury (0.01 - 0.11 μg/g); and zinc (15 - 59 μg/g). For a comparison with some other coastal harbours, see Section 3.2, and Figure 3.5.

Liverpool was identified as one of six sites on the Atlantic coast of Nova Scotia where significant quantities of tributyl tin (TBT) were used (Kieley 1989). The compound is no longer used as a marine coating in the area, but recent sediment samples from the slipway at the marine wharf had TBT concentrations in sediments of 420 μg/g dry weight (Hennigar and Garron 1992). Surface sediment samples from marine traffic areas (near a major fish plant) in 1994 had a TBT concentration of 0.019 to 0.026 μg/g dry weight, and corresponding concentrations from a ship

haulout were 3.6 to 14 μg/g (W. Ernst, Environment Canada, personal communication). These levels are significantly above backgrounds at a control site (Beaver Harbour) of < 0.002 μg/g dry weight (W. Ernst, Environment Canada, personal communication). No appropriate guidelines for acceptable levels of this chemical in sediments are available for comparison.

Cadmium concentrations in lobster digestive gland from the Liverpool area were the lowest reported for Nova Scotia Atlantic coastal sites in the early 1970s, ranging from 1.3 to 16.7 μg/g (average 5.19) wet weight (Uthe and Freeman 1980) (See Table 1.5 and Section 3.2.2).

3.8 LAHAVE RIVER ESTUARY

Oceanography and Biology

The estuary of the LaHave River is a narrow (1 km average width), inlet extending inland 24 km, immediately to the west along the coast from Lunenburg Bay, and opening on the Atlantic behind a chain of islands (LaHave Islands and West Ironbound Island). Depths range from up to 27 m at the mouth to 4 metres at the head of tide, where the Town of Bridgewater is situated (Figures 3.3 and 3.38). The estuary has a moderate tidal range of 1.6 to 2.2 m, and a flushing time of 38.7 hours (Gregory *et al.* 1993). The LaHave River provides a significant freshwater inflow, ranking fourth among Nova Scotia Atlantic rivers (monthly mean discharge of 34 $m^3 s^{-1}$). A narrow navigation channel is maintained from the town to the mouth of the river. The estuary is stratified in terms of salinity for much of its length, surface salinities ranging from 1.9 ppt at the town of Bridgewater to 24.9 to 26.5 ppt at the mouth; while salinities of 26.6 to 28.4 ppt occur in bottom water throughout the estuary (Figure 3.39) (Cranston and Buckley 1972). The outer approaches to the LaHave estuary have sand to gravel bottoms with muds nearshore on the northwest approaches (Piper *et al.* 1986) and in mid-channel at the mouth of the estuary (near LaHave) (Scarratt and Associates 1994b). Most of the upper estuary has a mud bottom, underlain by gravel in places and by sawdust in the vicinity of the shipyard at Dayspring. In areas of high loading of organic matter (e.g. ocean disposal site outside the estuary and at the LaHave Bakery wharf), a white bacterial mat (*Beggiatoa* sp) has been observed to occur, indicating low oxygen conditions and corresponding absence of animals in the sediments (Scarratt and Associates 1994b).

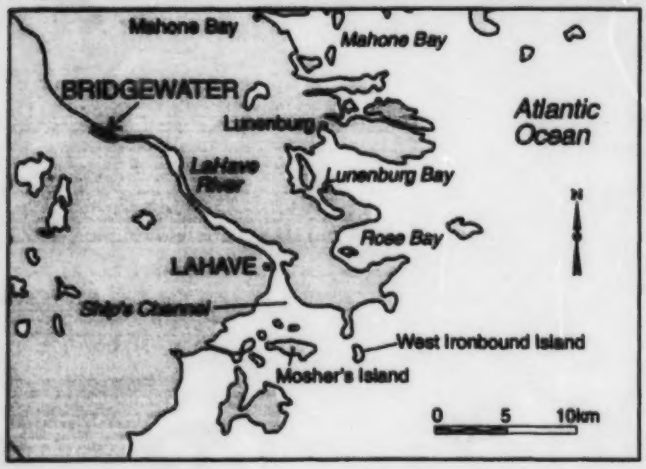


Figure 3.38. LaHave River Estuary and adjacent areas.

The LaHave estuary is bordered by small rural communities, forest and farm land. Bridgewater is the major population centre (population 1991 census, 7,250) and discharges treated sewage to the river. The area supports a major fish plant (Fishery Products International) at the mouth of the estuary and a major tire manufacturing facility on the LaHave River above the head of tide. Sewage from the Town of Bridgewater and contamination from sawdust from a shipyard, appear to be the only significant human impacts on marine organism communities in the LaHave estuary (Scarratt and Associates 1994b).

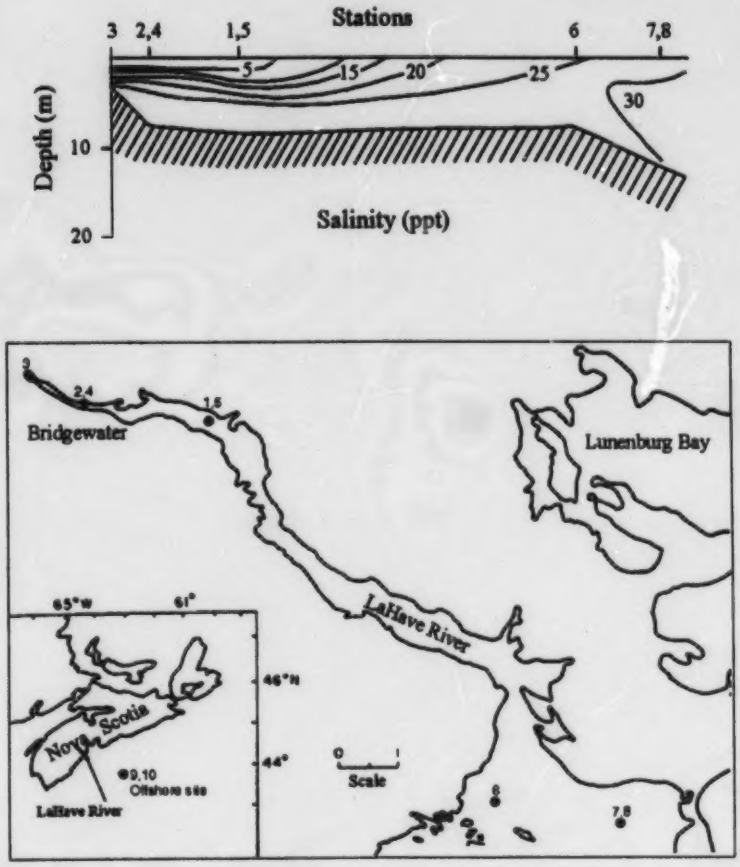


Figure 3.39. Salinity distributions in the LaHave River Estuary from Cranston and Buckley 1972.

Chemicals in Water, Sediments and Biota

In the early 1970s, concentrations of mercury in water and suspended particulate matter, and sediments of the LaHave River estuary were found to be elevated, exceeding levels at a nearby offshore site and above accepted environmental guidelines for water and sediments (Cranston and Buckley 1972; Wilson and Travers 1976) (Figure 3.39 shows the location of the offshore site). Levels in water in the estuary ranged from 0.036 to 0.380 μg/L compared with 0.058 to 0.088 μg/L offshore; in bottom sediments, 0.09 to 1.06 μg/g dry weight versus 0.09 μg/g; and in suspended particulate material 2.04 to 34.4 μg/g dry weight versus 0.002 to 0.03 μg/g (Cranston and Buckley 1972) (Figures 3.40 & 3.41). Mercury was suggested to have been introduced in the Bridgewater area from sewage and local use of bleaches (Cranston and Buckley 1972). Reductions in dissolved mercury seaward in the estuary, but increases in the particulate phase, reflect adsorption of the mercury by particles, and a peak observed in sediments in the upper estuary (Figure 3.41) shows areas of enhanced particle settlement (Cranston and Buckley 1972). Peak levels in water exceeded guidelines for the protection of marine life (0.1 μg/L) (McNeely *et al.* 1979), while some sediments exceeded the 0.75 μg/g guideline for disposal at sea under the Canadian Environmental Protection Act.

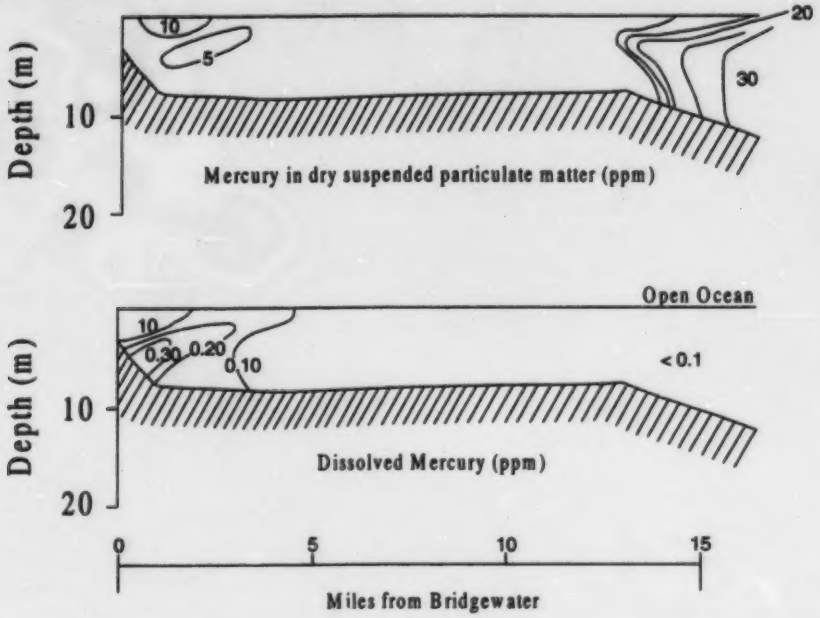


Figure 3.40. Mercury (dry suspended particulate matter and dissolved mercury) in the LaHave river estuary. For locations, see Figure 3.39 (from Cranston and Buckley 1972).

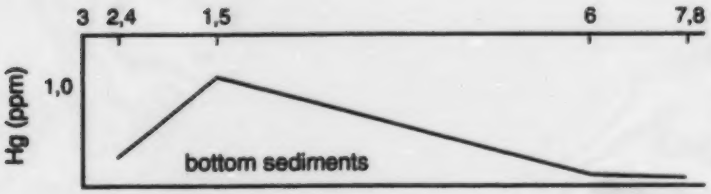


Figure 3.41. Mercury concentration in bottom sediments in the LaHave River estuary. For locations, see Figure 3.39 (from Cranston and Buckley 1972).

In 1994, Loring *et al.* (1996) found lower levels of mercury in sediments than observed in the early 1970s (Cranston and Buckley 1972), although still above background, suggesting that there has been an improvement in conditions in the harbour. Concentrations for cadmium (0.02 - 0.49 μg/g); copper (4 - 55 μg/g); lead (15 - 78 μg/g); and mercury (0.01 - 0.34 μg/g) were above background; while concentrations of zinc were considered to be in normal ranges (24 - 150 μg/g). The highest concentrations in sediments occurred in the upper part of the estuary near Bridgewater (Loring *et al.*, 1996). These levels are below ocean dumping regulatory levels of concern for ocean sediments for cadmium and lead. For background concentrations and a comparison with some other coastal harbours, see Section 3.2.2 and Figure 3.5.

Various contaminants were found at low levels, and lead occurred in significant concentrations, in mussels from LaHave, at the seaward end of the estuary, in 1989, as the result of an Environment Canada survey in the Atlantic Provinces and Newfoundland (Zenon Environmental Inc. 1989MS) (Table 3.5). Concentrations for key metals with the exception of lead (which was much higher) were well below those at an undeveloped Nova Scotia coastal site (Beaver Harbour, N.S.), and were slightly higher in copper, chromium and mercury, while comparable in

cadmium and zinc concentrations (allowing for differences in concentration resulting from wet weight or dry weight method of determination) to averages for mussels in United States coastal areas, and in the Gulf of Maine (Zenon Environmental Inc. 1989MS; O'Connor 1992; GMCME 1994) (See Table 1.4). Lead levels in the mussels approached the food quality guideline (CSSP 1992; USFDA 1990). The sampled mussels also contained methylene chloride (an industrial solvent), and di-n-octyl phthalate (a plasticizer) (Table 3.5). The presence of these industrial chemicals suggests that there is a local source of contamination in the estuary. Key PAHs, however, were below 100 ng/g or not present, while a scan of pesticides and aromatic amines detected only the carboxylic acid pesticide picloram at concentrations less than 0.03 μg/g wet weight (Zenon Environmental Inc. 1989MS). Picloram is a persistent herbicide, and the most-widely-used industrial brush control agent (right-of-ways on rail-lines, antenna sites, and power lines) in the Atlantic Region (G. Julien, Environment Canada, Dartmouth, Nova Scotia, personal communication). It was also the most commonly detected pesticide from the Atlantic Coast of Nova Scotia in the Environment Canada survey.

3.9 LUNENBURG HARBOUR

Oceanography and Biology

Lunenburg Harbour is situated at the head of Lunenburg Bay, a large coastal embayment on the south shore of Nova Scotia (Figures 3.3 and 3.4.2). The mouth of the Bay is flanked by several islands, the largest of which is Cross Island. The cross section of the Bay at the entrance between Cross Island and Rose Point is roughly U-shaped (in common with other inlets in the area which tend to have been worn into the bedrock by glacial activity and other processes), reaching depths of about 25 metres in mid-channel (Piper *et al.* 1986) (Figure 3.43). Extensive coastal shoals have developed in areas where drumlins occur on land, typically on the eastern side of the bay. Sand and gravel deposits predominate in the outer Bay, grading into gravel to boulder deposits in the outer margins, while muds occur in the inner and alongshore portions of the middle harbour (Piper *et al.* 1986).

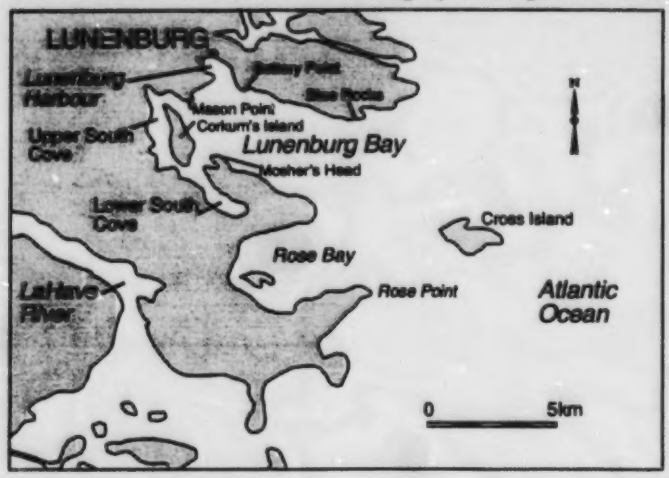


Figure 3.42. Lunenburg Harbour and adjacent areas.

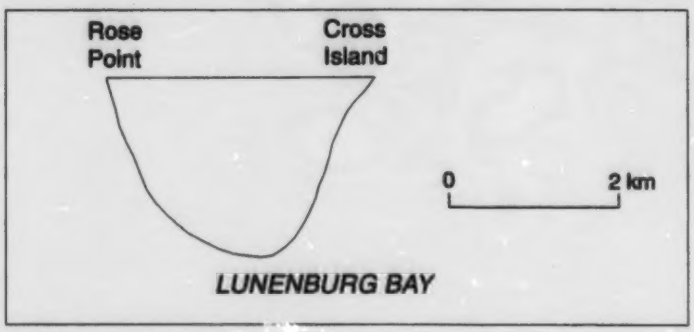


Figure 3.43. Cross-section of Lunenburg Bay (from Piper *et al.* 1986).

Lunenburg Bay has a semi-diurnal tide with a mean range of 1.6 metres, resulting in peak tidal currents typically less than about 0.2 m/s, and a relatively short flushing time of 54 hours (Gregory *et al.* 1993; Thompson *et al.* 1998). A major inlet (South Cove) is located on the south side of the Bay, and tidal currents exiting it result in a well-defined stream of fast-moving water from the mouth of the Cove crossing the harbour to the Lunenburg side (Thompson *et al.* 1998). The bay has relatively low freshwater inflow, peaking at 6.8 m^3/s in April (Gregory *et al.* 1993).

Seaweed and littoral animal communities are comparable to those found along the Atlantic coast (Moore and Miller 1983). At Blue Rocks on the northern shore of Lunenburg Bay, for example, the predominant algae are *Laminaria longicruris*, *L. digitata*, *Saccorhiza dermatodea*, and filamentous red algae (Moore and Miller 1983). A diverse community of bottom organisms

occurs in the harbour, and a lobster fishery (estimated annual catch of 4,230 kg) takes place at the mouth of the inner harbour area (Prouse 1994).

The Town of Lunenburg is one of the principal fishing ports on the Atlantic coast of Nova Scotia (population 2,780, 1991 census). Local industries associated with the Harbour include fish handling and processing, boatbuilding and repair, foundry and blacksmithing, and shipping. Together with the discharge of untreated domestic sewage and storm runoff from the town, and occasional dredging and disposal for channel and wharf maintenance (there is an approved ocean disposal site in the harbour), the port has a significant impact on the marine environment (Scarratt and Associates 1994b; Prouse 1994). There is little published information on the biology of the Harbour and Bay. In the inner harbour—particularly in the immediate vicinity of wharves, in areas which have been dredged, and near a foundry—the abundance of organisms and seaweeds is lower than in the outer harbour areas (Scarratt and Associates 1994b).

Chemicals in Water, Sediments and Biota

Lunenburg's role as a major fishing port, an industrial location and a population centre, has led to moderate level of chemical contamination in the harbour. Among other inlets on the Atlantic coast of Nova Scotia, Lunenburg Harbour consistently ranks among the most contaminated in terms of concentrations of a range of trace metals (Loring *et al.* 1996) and petroleum hydrocarbons in sediments (Levy *et al.* 1988). As in other Nova Scotia harbours, the most significant contamination frequently occurs where greatest human industrial activity and development occurs, chiefly in the inner harbour where the major industries, the Town of Lunenburg, wharves and other infrastructure are located. Other areas of the harbour are less likely to show anthropogenic impacts.

In the inner harbour, lead and zinc are 2 to 3 times background concentrations (Prouse 1994), and were similarly elevated in the early 1980s (OceanChem 1985) (Table 3.36). A recent survey of sediments by Loring *et al.* (1996) ranked Lunenburg Harbour as one of the most contaminated of ten inlets on the south coast of Nova Scotia, finding concentrations of various metals which were significantly above background, including: cadmium (0.24 - 1.71 μg/g); copper (11 - 108 μg/g); lead (16 - 73 μg/g); mercury (0.03 - 0.39 μg/g); and zinc (49 - 304 μg/g). Nonetheless, levels of cadmium and mercury were below ocean dumping guidelines in the early 1980s (OceanChem 1985) and in 1988, although at that time, mercury levels at some sites were near the ocean dumping limits (Prouse 1994). For background concentrations and a comparison with some other coastal harbours, see Section 3.2.2 and Figure 3.5.

Table 3.36. Concentrations of key contaminants in sediments from Lunenburg Bay (from OceanChem 1985).

Concentration (ug/g dry weight)	
Metals	
Cadmium	0.08 - 1.3 (avg. 0.77)
Copper	14 - 137 (avg. 72.7)
Mercury	0.06 - 1.05 (avg. 0.46)
Lead	14.7 - 188 (avg. 74.0)
Zinc	46.1 - 523 (avg. 204.0)
Chlorinated Organics	
PCB (Total)	< 5 - 2,426 (avg. 131.0)
DDT (Total)	< 0.005 - 0.104 (avg. 0.019)

In addition to metals, average petroleum hydrocarbon concentrations in sediments in inner Lunenburg Harbour in 1978 (23.7 μg/g, range 1.38 to 72.7 μg/g dry weight) are significantly elevated over background in smaller ports (which typically average 10 μg/g) and are comparable to some major industrial ports in Atlantic Canada (e.g. Sydney, see Figure 3.6). Highest concentrations are found in the vicinity of the Town of Lunenburg waterfront and lower concentrations at Battery Point (Levy *et al.* 1988). Lower levels (up to 21 μg/g oil and grease) were found in the harbour in the early 1980s (OceanChem 1985).

Lunenburg Harbour sediments also show localized concentrations of PCBs (up to 2,426 ng/g, significantly above the ocean dumping limit of 100 ng/g), detected in the inner harbour in the early 1980s (Table 3.36) (OceanChem 1985). Lunenburg was also identified as a site of significant usage of tributyltin (TBT) in shipbuilding and repair (Kieley 1989). Levels in sediments from areas of Back Harbour (an adjoining harbour east of Lunenburg) used by pleasure craft and small fishing vessels were 0.024 μg/g dry weight in 1988 and 0.012 μg/g in 1994, while areas for pleasure craft had levels of 0.01 - 0.02 μg/g. Levels of TBT in blue mussels from Back Bay showed significant contamination—80.8 ng/g wet weight (W. Ernst, Environment Canada, personal communication). With adjustment for differences in wet/dry weight reporting of data, this level is roughly five times the average reported in mussels from the coastal United States (O'Connor 1992; Table 1.4).

Several contaminants, including industrial chemicals and pesticides have been found in analyses of mussels from Lunenburg Harbour carried out as part of a regional monitoring program by Environment Canada in 1989 (Zenon Environmental Inc. 1989MS) (Table 3.5). Concentrations for key trace metals were well below those found in an undeveloped site (Beaver Harbour, N.S.), but levels of copper, chromium, mercury and lead (adjusting for wet/dry weight measurements) were above averages for United States coastal areas, and levels in the Gulf of Maine (Zenon Environmental Inc. 1989MS; O'Connor 1992; GMCME 1994) (See Tables 1.4 & 3.5). Methylene chloride (an industrial solvent), and two plasticizer chemicals (bis (2-ethylhexyl) phthalate and di-n-octyl phthalate) were also detected. The presence of these industrial chemicals suggests that there is a local source of contamination in the harbour. Key PAHs were below 100 ng/g or not present, while the carboxylic acid pesticide, picloram, and the nitrogen/phosphorus pesticide, carbofuran, were also detected (Table 3.5). Picloram is a widely-used industrial brush control agent. Other pesticides and aromatic amines were not detected in mussel tissues (Zenon Environmental Inc. 1989MS).

3.10 ST. MARGARET'S BAY

Oceanography and Biology

St. Margaret's Bay is a large (10 x 16 km, area 138 km^2), roughly triangular inlet on the south coast of Nova Scotia, about 40 km west of Halifax (Figure 3.3). The bay has a sinuous coastline containing numerous islands and passages, the result of submergence of a glacially-modified coastline (Figure 3.44). Beaches consist of coarse sand and glacial erratics and the sediments in the central area range from sand to silt to clay, with silty sand or silty clay predominating. Bottom topography is relatively uniform with only minor irregularities except off headlands where there are scattered ledges and shoals, including bedrock, boulders and coarse gravel and sand (Figures 3.45 & 3.46) (Sharaf El Din *et al.* 1970; Piper and Keen 1976). The Bay is roughly U-shaped in profile, reaching depths of 80 metres near the mouth on the west side. A broad sill at 45 metres occurs outside the Bay.

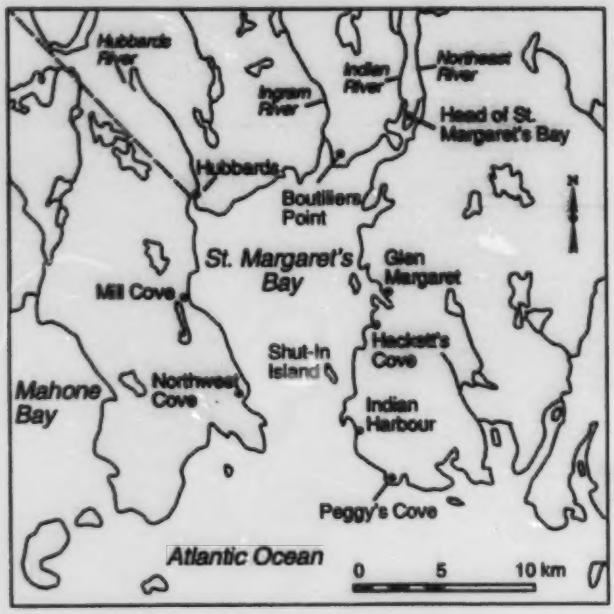


Figure 3.44. St. Margaret's Bay and adjacent areas.

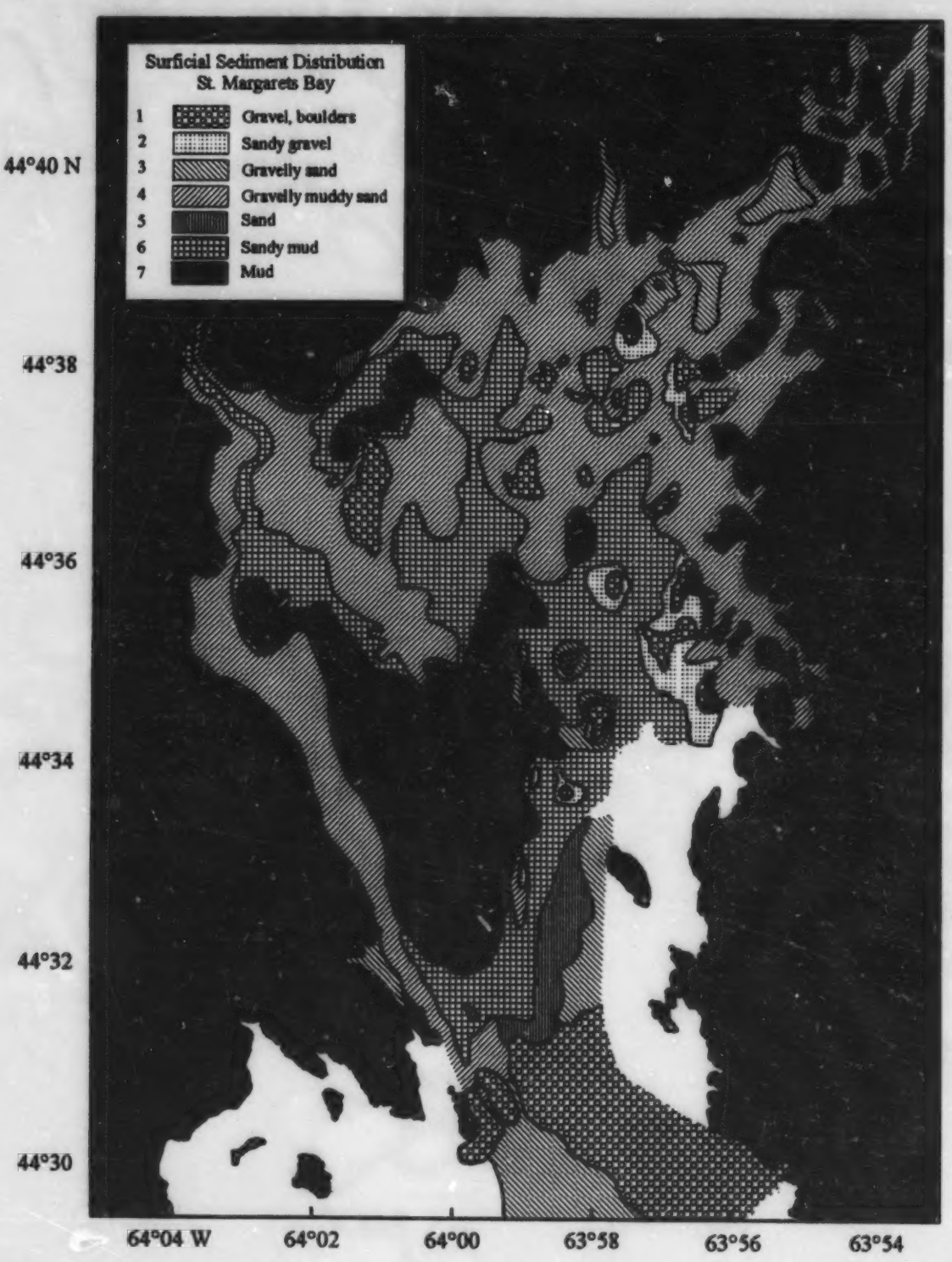


Figure 3.45. Distribution of surficial sediments in St. Margaret's Bay (from Piper and Keen 1976).

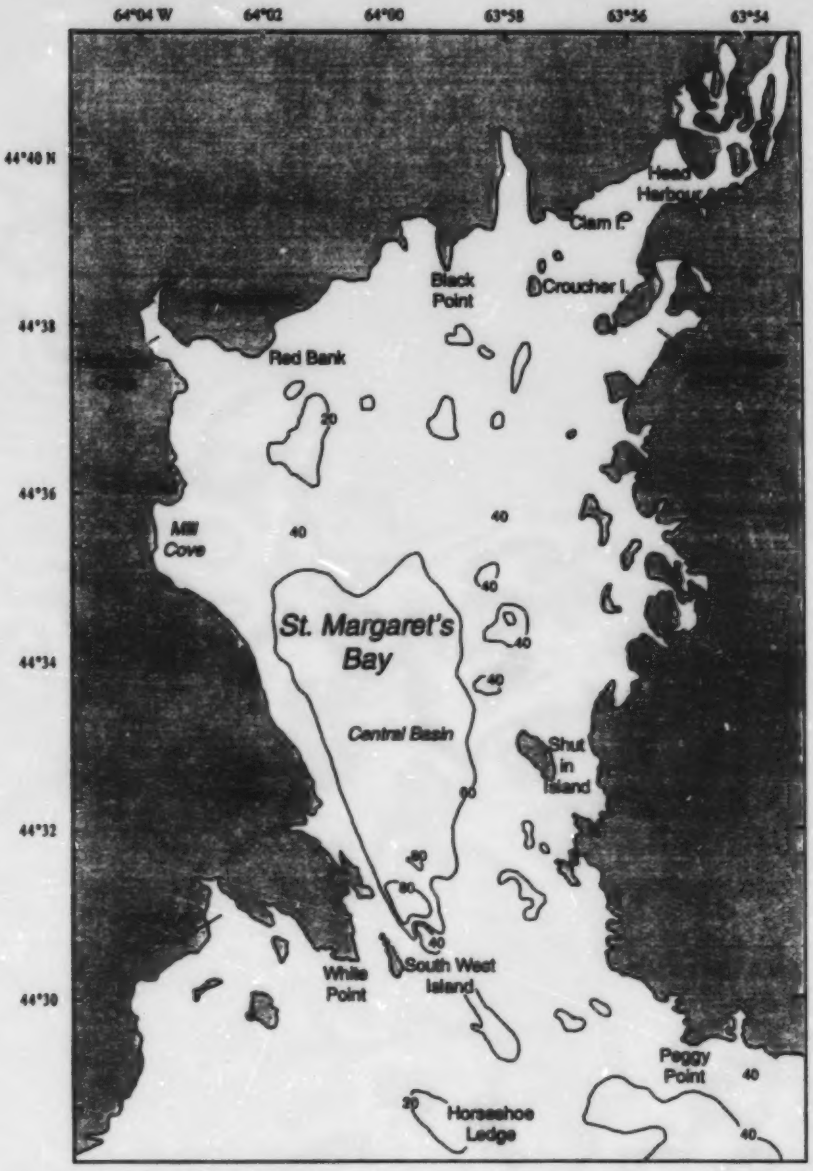


Figure 3.46. Depth contours (metres), St. Margaret's Bay, Nova Scotia (from Sharaf el Din et al. 1970).

Five rivers flow into the basin: Hubbards, Ingram, Northeast, Indian and Hosier, together contributing about 75% of freshwater input, the remainder coming from smaller watercourses and land runoff. The bay is typically stratified year-round, having a strong seasonal thermocline in summer (surface temperatures of 18 °C or more, and 2-4 °C at bottom) with salinity in bottom waters typically 31.6 to 33.0 ppt, and surface values of 23.3 to 31.3 ppt, the lowest occurring near freshwater sources (Sharaf El Din *et al.* 1970) (Figures 3.47). The northern end is the only part of the Bay to freeze in winter, because of the reduced salinity due to freshwater sources. Tidal range is typically 1 to 2 metres, and flushing time for the Bay is about 6 to 10 days for

surface water, and for bottom water, 28 to 35 days (Sharaf El Din *et al.* 1970; Gregory *et al.* 1993). Passage of weather systems can result in rapid flushing of the surface layers, as occurs in other inlets along the coast (e.g. Bedford Basin, Canso Strait) (Heath 1973; Platt *et al.* 1972). A net counterclockwise circulation occurs and tides are the main factor influencing currents (Sharaf El Din *et al.* 1970).

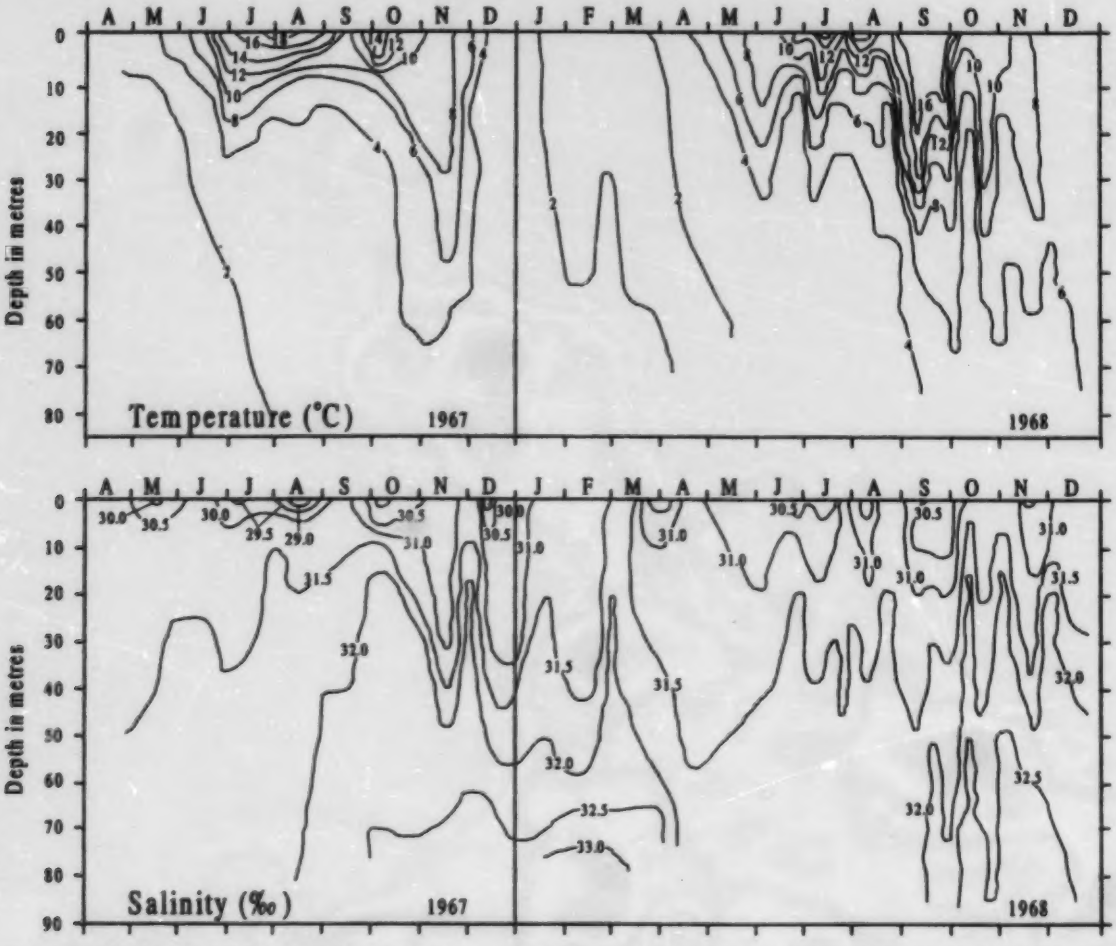


Figure 3.47. Seasonal variation of temperature and salinity with depth in central St. Margaret's Bay in 1967 and 1968. (from Sharaf el Din *et al.* 1970).

St. Margaret's Bay has a diverse biological community including seaweeds in the intertidal (between low and high tides) and littoral (from low tide to roughly 30 m) and phytoplankton communities typical of the Nova Scotia coast. Seaweeds in St. Margarets Bay account for about 75% of the total primary production in the Bay (Mann 1972), while phytoplankton account for the remainder (Platt 1971 from Marine Ecology Laboratory 1980). Benthic communities are diverse and typical of the Atlantic coast (Hughes *et al.* 1972; Mathieson *et al.* 1991). Coastal species of fish (e.g. Atlantic herring, Atlantic mackerel, Spiny dogfish) typically frequent the bay. Occasionally warm-water species have occurred there, thought to have been spun off from

warm Gulf Stream eddies impinging on the outer continental shelf. No overview is available for commercial fisheries of St. Margaret's Bay.

St. Margaret's Bay does not have major centres of industrial development, although several ports support fishing activities and numerous small communities occur along the shore. Key fishing villages and population centres include Mill Cove (1991 census, 357), Hubbards (499), Hackett's Cove (413), Boutilier's Point (648), Head of St. Margaret's Bay (420 (1986)), Indian Harbour (317 (1986)), Northwest Cove and Glen Margaret (both below 250). Important environmental concerns in the Bay include coastal residential development and the associated potential for sewage contamination and non-point source pollution, as well as use conflicts with aquaculture and fisheries activities; and wastes associated with fishing vessels and fish processing facilities.

Chemicals in Water, Sediments and Biota

There is little information on occurrence of contaminants in the environment of St. Margaret's Bay. Petroleum hydrocarbon concentrations measured in water in 1975 were comparable to those of oceanic waters (Gordon *et al.* 1978) (Table 3.9, Section 3.3.5). Hargrave and Phillips (1976) considered the Bay an unpolluted environment when they analyzed DDT residues in fish and benthic invertebrates from both shallow and deep areas of the Bay. DDT and metabolites were the only organochlorine compounds present in detectable amounts in marine fish and invertebrates from St. Margaret's Bay, and levels were among the lowest recorded of any area. DDT levels were also low (less than 1 ng/g wet weight) in copepods from the area (Darrow and Harding 1975). Mackerel from St. Margaret's Bay had relatively low mercury concentrations of less than 0.005 to 0.09 μg/g wet weight (compared with acceptable levels in fish tissues of 0.5 μg/g (Eaton *et al.* 1986) (Freeman *et al.* 1974)).

As in other inlets, it is expected that there is some localized contamination adjacent to wharves, centres of population and fish plants in St. Margaret's Bay, but no information on these areas is available.

3.11 CONTAMINANTS IN COASTAL AREAS—SUMMARY AND CONCLUSIONS

The contamination issues affecting Nova Scotia coastal areas are the same as for other areas of the world, but are generally on a smaller scale due to our smaller population and level of industrial development. While most coastal areas could be classed as uncontaminated, seaports, fishing and industrial centres where human activity is greatest, have experienced coastal contamination problems. Nova Scotia has at the same time examples of one of the most contaminated harbours in the world in terms of certain contaminants (Sydney Harbour) as well as several industrial harbours which have contamination problems on a par with those typical of heavily industrialized centres the world over—while at the same time, much of the Nova Scotia coastline is at or near baseline contaminant levels. Occasional assessments show levels of a range of contaminants in water, sediments and biota, which are below those found elsewhere in the world and often below natural background. Nova Scotia's low population density and comparative lack of industrialization have contributed to this situation, which is both an opportunity and a challenge to maintain this high environmental quality in the face of increasing population growth and industrialization.

4. CONTAMINANTS IN THE MARINE ENVIRONMENT OF THE SCOTIAN SHELF AND ADJACENT COASTAL AREAS — SUMMARY AND CONCLUSIONS

Although the intent of this report has been to summarize existing information on contaminants, some general comments are included here for completeness to evaluate the state of contamination on the Scotian Shelf and its adjacent coastal waters, and to compare it to other areas.

Compared to other regions of the world, and with a few exceptions, levels of contaminants in the marine environment of the Scotian Shelf and adjacent coastal waters are lower than those found in waters of other industrialized coastal nations, in many cases approaching baseline conditions. This is not surprising, considering the generally low levels of industrialization and population development here, but also because of Canada's regulatory regime, which has led to controls on sources and releases of contaminants. Some contaminants show this pattern well. For example, levels of metals in soft bottom sediments in a range of harbours on the coast of Nova Scotia are below baseline levels for uncontaminated sediments around the world (see Section 3.2.2; Loring *et al.* 1996). Levels of metals in offshore waters of the Scotian Shelf are at or near background levels, low enough in some cases that natural processes which release contaminants at sometimes low levels into the environment (e.g. diagenesis or chemical alteration of manganese in deep basins of the Scotian Shelf) can be detected. Nevertheless, the influence of other industrialized parts of Canada in raised contaminant levels in waters reaching the Scotian Shelf from the Gulf of St. Lawrence, is detectable.

For other contaminants, human activity has left more of a mark on the marine environment as evidenced by elevated concentrations in both coastal and offshore areas. In offshore waters, marine traffic and releases of hydrocarbons from ballast, accidental spills and normal operating losses, have led to detectable levels of hydrocarbons there. Awareness of the problem, and tighter legislative and regulatory controls have led to reductions in releases and consequent lowering of levels in the environment. Monitoring studies carried out from the 1970s to the 1980s appear to suggest that concentrations of hydrocarbons in offshore waters are declining (Levy 1984; 1988). Nonetheless, shipping practices including pumping into the ocean of ship bilge and ballast, accidents, spills and routine operations, continue to cause the release of oil into the marine environment, where they lead to more serious problems such as the oiling and subsequent mortality of seabirds, in addition to contributing to overall levels of hydrocarbons in seawater. There is also no indication that the trend in marine litter, which originates mostly from shipping and fishing activity (although efforts are being made to reduce it) is downward.

Offshore hydrocarbon development, the only major industry other than shipping and fishing which releases contaminants into the offshore environment, is on the rise in the Nova Scotia offshore. Offshore facilities typically release contaminants at various stages in the operations. Tighter regulations on drilling activities have reduced or limited many of the releases (e.g. drilling muds using an oil base) to the environment, and ensured tight controls on levels of hydrocarbons in 'produced water', one of the main longterm discharges of oil and gas production facilities. However, contaminants such as trace metals, nutrients, and hydrocarbons released by production activities, spills, and produced water, as well as releases from rig tender and supply

vessels, will continue to enter the marine environment and will likely lead to some increases in contaminant levels in offshore waters in future. The impacts of these activities are favoured by large dilution factors offered by the vast Atlantic Ocean, and while the overall levels of contaminants resulting from them are likely to be small, they will likely be detectable as differences from background levels if monitoring surveys are undertaken.

Atlantic coastal areas of Nova Scotia have more serious contamination, although it is typically highly localized in and around major harbours and fishing ports, centred on industrial activity and human population development concentrated there. Coastal activities are buffered from many of the effects of development by the presence of the relatively uncontaminated offshore waters which wash the Nova Scotia shores, and which exchange continuously, taking away and diluting contaminants. As a result, for example, the waters of Halifax Inlet—a water body which has been heavily impacted overall by human activity— are relatively uncontaminated with trace metals (see Figures 3.15 and 3.16, Section 3.3.5). Sediments are a different story, owing to the tendency of contaminants to adhere to particles and to settle out of the water column, where they become incorporated in sediments and lead to high concentrations there. To use Halifax Inlet and the adjacent Northwest Arm as examples, these areas show elevated levels of some contaminants which are on a par with those in some of the major harbours in the world. The fact, however, that Halifax Inlet continues to function as a relatively healthy marine system, shows that levels of contaminants measured in one compartment of the environment only present part of the picture. Nonetheless, even at low levels contaminants may be having effects which we are not yet aware of. Overall awareness of the need to reduce releases of contaminants by various industries and human activities, as well as increased awareness of particular problems identified by studies of Halifax Inlet, have perhaps saved it from becoming an example of more serious environmental degradation. However Halifax and other major harbours on the Atlantic Coast of Nova Scotia still suffer from significant inputs of sewage and its associated mix of contaminants, and organic loading which can lead to habitat degradation, and in most of these areas, to levels of fecal coliform bacteria above guideline levels which suggest risk to human health.

In other coastal areas, contamination problems have been identified and we are still working on correcting them—continued monitoring is required to determine if the environment is recovering. The South Arm of Sydney Harbour in northern Cape Breton Island, is severely contaminated with a wide range of contaminants, but particularly PAHs from a coking operation tied to the Sydney Steel plant, PCBs from unknown sources (likely indiscriminant dumping), trace metals, and organic carbon from coal fines and sewage. In terms of PAH contamination, Sydney Harbour is one of the most severely contaminated sites in the world; levels of contaminants in biota there, particularly lobster, led to the cessation of the commercial fishery. The many sources of contamination are typical of cases of industrial pollution, and are one of the reasons that the management of the cleanup of this harbour has been lengthy—over two decades since the problems were first acknowledged and acted upon. Nonetheless, monitoring has shown some reductions in levels of particular contaminants. As is also the case in Halifax Inlet, however, contaminants trapped in sediments will be impossible to remove and will likely remain for the foreseeable future.

Apart from major industrial harbours, smaller ports have in past experienced contamination problems which were sometimes severe. While some of the problems (e.g. contamination of

sediments in coastal marinas and ship maintenance facilities with tributyltin; and oil spilled along the coast as the result of tanker accidents) continue to be monitored, others, such as the severe PCB contamination detected in Petit de Grat Harbour in the late 1970s have not been revisited.

Levels of specific man-made contaminants are of particular interest because either they were designed to have disruptive effects on biological organisms (e.g. DDT, pesticides) or are members of similar types of chemicals (e.g. PCBs, chlorinated hydrocarbons) which have the potential to cause serious harm to biological organisms. Monitoring at several levels of the food chain, but in particular in seals, has shown declines in concentrations of these contaminants on the Scotian Shelf, mirroring patterns found in mammal tissue and bird eggs elsewhere. While this represents a success story for these chemicals, there are others whose release into the environment is a concern but whose presence is not as closely monitored. No monitoring has been done of contaminants in other trophic levels on the Scotian Shelf.

The future can be optimistic for the marine environment on the Scotian Shelf and adjacent coastal areas, in terms of contamination if we are careful and manage human activities responsibly. We have a good starting point and are reasonably aware of the needs and what must be done to live and carry on our affairs productively and at the same time minimize our impacts on the environment. We hope that this report will be one of the many to help define from where we have come, and to guide us on our future direction.

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